BASIC STUDIES IN SCIENCE

Science Problems

For the Junior High School

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BOOK 3

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Teacher's Guidebook for Science Problems 3

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HOW ARE YOU CHANGING?

A VERY wise man once said, "To live is to change." From your study of living things, you know one thing that he meant. You know that the body of every living thing constantly changes from the time it is born until it dies. But something else besides your body changes. Your mind changes, too. Every year you have new experiences, and from these experiences you learn things and get new ideas.

A few years ago the boys and girls of the science classes in a large city high school were asked to answer this question: "How has the study of science changed you?" Here are some of the things they said:

"I learned of the many ways in which man has harnessed nature to do his work. . . .By use of electricity he makes darkness into artificial light."

"The study of science led me to cross-pollinate flowers myself and watch the results."

"I bought a microscope to better continue my experiments."

"On trips now I look for fossils and evidence of change."

"I am now more interested in the habits of insects, flowers, and trees."

"In science I discovered how little I know."

"It made me want to see below the surface and know the inner, secret workings of things."

"All the theories given in science were backed up by evidence. It has made me look for evidence in everything."

"It taught me that only after many observations am I capable of making a true statement."

"Since studying science I don't say a thing is so, for sure; but as far as I know, it is so."

"I found that prejudice helps to twist the facts around and so makes the value of an experiment less."

"I learned that great men, like Aristotle even, had wrong ideas, and thus my own ideas were encouraged."

"I learned to work more systematically."

"I now read biographies on the lives of scientists and articles containing scientific facts, which before were of no interest to me."

"Now, with a knowledge of some science, I can enjoy and understand scientific discussions in books."

Most people think the changes these boys and girls saw in themselves are good changes, and that is one reason why you have been given a chance to study science.

Like *Science Problems, Book 1* and *Book 2*, this book will help you learn a great deal about the causes of things —about how nature works. In it you will read about plants and animals, about the energy of coal and oil and waterfalls, and about sound, light, and electricity.

As you would expect, scientists have learned a great deal about these things—much more than we could possibly tell you in one book like this. But what is more important to you is this: The knowledge of how nature works has helped scientists and inventors produce all sorts of new things—new varieties of plants and animals, water-wheels, complicated engines, automobiles, printing presses, electric batteries, generators and motors, and radio apparatus. All these inventions help man control the energy and materials of nature and make them do what he thinks he wants done.

But there is another side to man's use of nature. By cutting forests, cultivating land, and raising animals he

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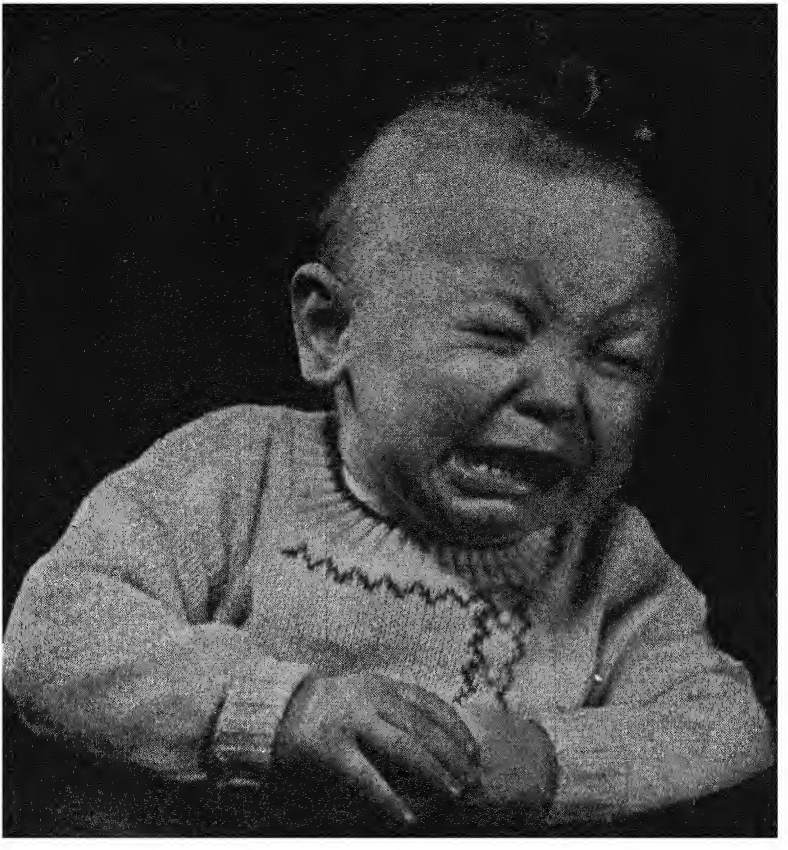


FIG. 1. This little chap is having his troubles, and he is letting everyone know about them. But before you laugh at him, read pages 30-31; you may find that even now you sometimes behave like this little fellow. And in the other pages of Unit 1 you will learn many things to explain why you behave, or act, the way you do. You will also discover that all living things, including even plants, behave in certain ways. (Black Box Studios)

UNIT ONE

UNIT 1
HOW DO LIVING THINGS BEHAVE?

INTRODUCTORY EXERCISES

1. What does the word *behave* mean to you?

2. Explain as well as you can what you do when you think. List the things you have done today that require thinking.

3. You have many habits. Make a list of them and think about each one. How are habits valuable to you? How may a habit be harmful?

4. Do you know of any kind of animal that you think can learn to do things? If so, what can it learn, and how does it learn?

*5. What sense organs do you have that inform you what is going on around you?

*6. What is a stimulus? Name three kinds of stimuli. Do all living things respond to stimuli?

7. What reasons can you give for believing or not believing that a plant can change itself when changes take place in its surroundings?

8. Some people believe that animals such as dogs and horses can think. Do you believe that they can? Tell exactly why you believe as you do.

9. If you have ever taught an animal to do a trick or if you know how animals are trained, tell exactly what must be done to teach the animal. Try to explain what makes the animal learn.

*10. In what two ways is man's body superior to the bodies of all other animals?

FIG. 2. Something has happened, and these lions are ready for action. Through their eyes, ears, or noses, or through all three, messages of some kind have come to them, and they are showing it in their behavior. (Field Museum of Natural History)

LOOKING AHEAD TO UNIT 1

IT IS late in the afternoon. At different places on the earth there are five animals: a lion, a python, a frog, a woodpecker, and yourself. Each of these animals has the same sensation—an empty feeling below the "belt line." You know this means that you are hungry. What the other animals feel about it, we cannot say, but we can watch what they do.

The lion moves its head from side to side and restlessly sniffs the air. Suddenly it "freezes." Apparently it smells something. Over to the left there is a small antelope. Silently, but swiftly, the lion stalks its prey. Closer and closer it gets. Then with two leaps it reaches the animal, and its strong, cruel claws and sharp teeth soon make an end of the antelope. The lion has had its dinner.

In a near-by forest a long, sinuous body of bone and muscle slithers along the ground. Presently it comes to a trail made by animals on their way to water. Close to this trail is a tree with an overhanging branch. Up the tree goes the python. It wraps its tail around the tree trunk and hangs there, ready to launch itself upon any unwary

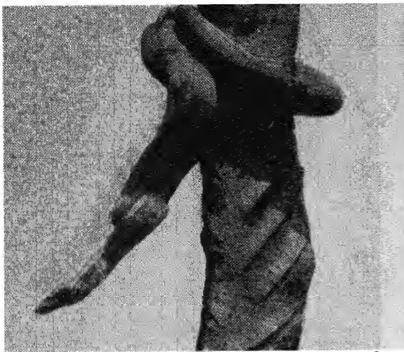


Fig. 3. Something has aroused this python, and he is ready to act; in other words, he is responding to something that has happened in him or around him. (Chicago Museum photo)

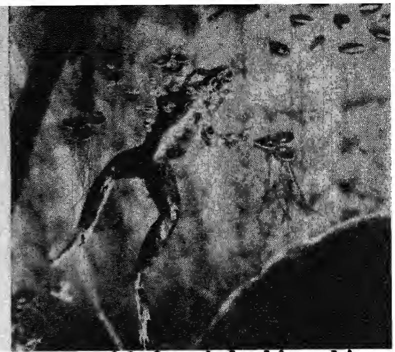


Fig. 4. This frog is looking things over. Some message from his surroundings may send him scooting to the bottom, or he may find everything all right and climb out on land.

animal that passes down the trail. We know what will happen. The python will loosen its hold on the tree and drop on the unsuspecting animal below. Then it will wind its coils around the body of the animal and slowly squeeze the life from it. The python will have its meal.

The scene now shifts to a pool. There is a little movement in the water, and a head pokes itself above the surface. Everything must look all right, for the head comes closer to the shore, and a frog crawls out on the bank. There it sits perfectly motionless. Presently an insect comes buzzing around its head. Still there is no movement from the frog. Then something flashes out of the frog's mouth and disappears almost in the same instant. There is no insect buzzing around the frog's head now. The frog has had its dinner.

And now I hear a rat-tat-tat just outside my window. A woodpecker is drilling a hole in a near-by tree. Presently it stops. I cannot see what is happening, but I know what is taking place. A woodpecker has located an insect larva under the bark of the tree. When the hole is deep enough, a long, flexible sticky tongue will shoot into the hole, and when it comes out again, the larva will be sticking to it.

All of this time you have been bothered by an empty feeling. You go to the refrigerator and get a bottle of milk. Next, you raid the cookie jar. And now you, the lion, the python, the frog, and the woodpecker all feel much better.

How do the stories that you have just read help you see more clearly what this unit is about? First of all, each animal had the same feeling, a feeling of hunger, and each animal responded to this feeling by looking for food. It is hard to describe the feeling of hunger, but you know what it is like. It is an unpleasant feeling, and it calls for some kind of action on your part. When you eat food, the unpleasant feeling disappears. Your *response* to the feeling of hunger is to find food and put it into your body. Other animals respond in the same way to this feeling of hunger.

FIG. 5. An inner feeling of some kind sends this flicker hunting for food. (L. W. Brownell photo)

If you will think about the things you do every day, you will find that every move you make, every activity you carry on, is caused by something that is going on in your body or about you. You are hungry; you eat. You are thirsty; you drink. An automobile horn sounds close behind you; you jump out of the way. You touch a hot stone; you jerk your hand away. Someone asks you a question; you answer it. Your response to a situation is called your *behavior*. Other animals respond to situations, too. When you study about behavior, you must always consider two things: (1) what the situation is to which the

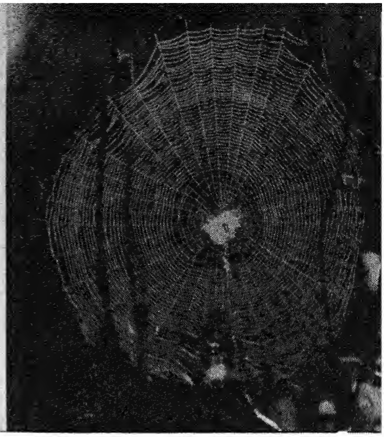


Fig. 6. Potter-wasp egg nests **Fig. 7. A spider's web**

The kinds of nests and homes that animals build are all a part of their behavior. Year after year and century after century they go on building in exactly the same way. No one teaches them; they seem to be born knowing how to do these things.

animal is responding; that is, what makes the animal act the way it does, and (2) what the animal does, or how it behaves in response to this situation.

Now let us go back and study the behavior of the lion, the python, the frog, the woodpecker, and yourself in response to the feeling of hunger. The behavior of each of the animals described was different from that of the other animals. Each animal had its own way of finding food, capturing its prey, and eating it. You can see one reason why the responses were different. Each animal is built in a certain way. It has certain parts that it uses to get its food. The way an animal acts when something happens to it thus depends to some extent upon the structure of its body.

But we cannot explain the different kinds of behavior of living things solely by the kinds of parts that make up their bodies. For example, you and I are not much different in structure from a chimpanzee. The chimpanzee has the same internal organs that we have. It has eyes, ears, a nose, arms, lips, and fingers. It can be taught to

take care of a baby, sweep, use a knife or fork, and drink from a bottle. But you can do many things that the chimpanzee can never do. You can read, spell, add, plan and build a boat, and play the piano. Of course you had to learn how to do these things. But a chimpanzee can never learn to do them. Do you know why this is true?

When you watch the behavior of animals, you find that there is a great difference in the way they respond to a situation. Some animals can make only one kind of response to a situation. They can never learn any other way of behaving. Some animals can remember what has happened in the past and can use this past experience to respond again in the same way to the same kind of situation. They can learn from experience. In other words, some animals are more intelligent than others.

POLICE TRAIN DOGS TO HEED ORDERS SENT TO THEM BY RADIO

SYDNEY, Australia, Feb. 3.—The Sydney police are training Alsatian dogs to obey radio commands. Zoe, the only dog fully tested, has reacted perfectly to a set carried on a back saddle. The set weighs eight pounds and includes batteries, a loud speaker, and an aerial.

Zoe has carried out the following radio orders: Fire a revolver, climb an eight foot trestle and return backward, turn on a tap and fill a water can, and remove and replace collar.

When the set first was strapped on her body, Zoe was amazed as the sound of a voice came from it, but quickly accepted the instructions.

FIG. 8. Watch newspapers and magazines for stories about how and why plants and animals behave the way they do.

In this unit you will learn how animals respond to situations, why some animals are more intelligent than others, how animals learn, and some of the reasons why you yourself behave as you do. You will find out, also, how plants behave. Yes, plants can respond to changes in their environment, too. Every living thing can adjust itself in one way or another to what is going on around it.

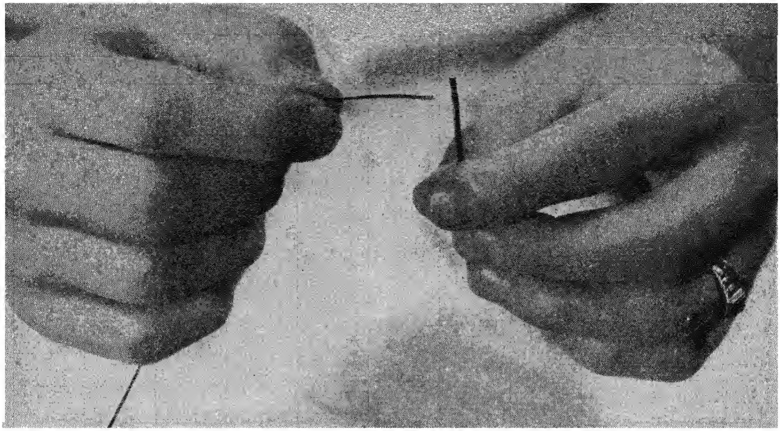


FIG. 9. Because of his hands, man can do things that no other animal can do. Monkeys, chimpanzees, and gorillas have hands much like man's, but man's hands are better developed and he can move his fingers and grasp things more easily. Do you see how such hands, directed by a superior brain, help man make things? (Hinsey photo)

Problem 1:

HOW DO HUMAN BEINGS BEHAVE?

IT HAS probably never occurred to you what a marvelous being you are. Think of the things you can do. You can control the movements of your arms, legs, and fingers. As a result, you can throw a baseball, hit a golf ball, walk, run, jump, whittle out a boat, sew on a button, or play a piano. You can talk and write; thus you can tell others what you are thinking. You can hear and read; in this way you can learn what other people want to tell you. You can remember things that happened yesterday or a year ago. You can profit by the experiences you have had. You can plan things in your mind. You can decide what to do long before you do it, you can remember your plan, and you can know that what you do will be the right thing. No machine and no other kind of living things can even begin to do all of these things.

To do all of these things you had to be able to learn. You have eyes and can see. But you had to learn to read. If you have a baby brother or sister, you know how little he can do for himself. About all that he can do is to

make a noise when he is hungry, when something is hurting him, or when he wants attention, and eat when he is offered food. Most of the things you do every day are things that you have learned to do. You have to learn how to behave and control yourself.

Before you can understand how you learn, you will have to get a few ideas about the way your nervous system works. It is your nervous system that really manages your behavior and gives you control of yourself.

HOW DO YOU KNOW WHAT IS GOING ON INSIDE YOUR BODY AND AROUND YOU? Before you try to solve this problem, think a minute about what is going on around you and in you. To help yourself do this, answer the fourteen questions on this page and the next. For the first eleven questions close your eyes after reading the question; then answer it. Then ask yourself, "How do I know this?" The following example will show you what to do.

Answer this question: "Am I standing, sitting, or lying down?" Now close your eyes and answer the question. Then ask yourself, "How do I know this?" Let's suppose that you were sitting. The answer to the question is, "I am sitting. I know this because I can feel my body pressing against the seat. I can also feel that the weight of my body is not pressing against my feet or over one whole side of my body. So I cannot be standing up or lying down."

Now that you know what to do, answer the following eleven questions. Be sure to close your eyes so that you cannot get the information with your eyes.

1. Are both of my feet on the floor, or do I have my legs crossed?

2. Does the chair in which I am sitting have a back and arms? Does it have a cushion in the seat?

FIG. 10. Guided by her "Seeing-Eye" dog this woman was one of the first persons to cross the great Golden Gate bridge at San Francisco. Here she is shown getting the "feel" of the enormous steel cables that help support the bridge. People who are blind know much more of what is going on around them than you might think. Their senses of touch, hearing, and smell become very keen. (Acme photo)

3. Am I holding a book?
4. Is the air hot, cold, or just comfortable in temperature?
5. Is there a current of air moving by me?
6. Is there an automobile going by outdoors?
7. Is the wind blowing hard?
8. Are there any onions being cooked near by?
9. Am I tired?
10. Am I hungry?
11. Am I thirsty?

Answer the next three questions with your eyes open:

12. Is there anyone else in the room?
13. What is the color of the walls of the room?
14. How wide is this room?

If you did what you were told to do, you were probably surprised at how much you could learn about what was going on inside your body and what was going on around you, even though you could not see. Now let us see how you were able to know all of these things.

First, think of the information that you have about things going on at a distance from you. With your eyes you are able to tell whether anyone is in the room. Light from the sun or from an electric lamp strikes the person, and this light is reflected to your eyes. The light passes through the front of your eye to the back of your eyeball, where it falls upon some material that is sensitive to light. Chemical changes take place in this material and stimulate a nerve connected with it. A message then starts along this nerve. This nerve carries the message to a certain part of the brain. From here the message travels to other parts of the brain. Something happens in the brain. Nobody knows just what does happen, but the result is that we see the person. We see how tall he is, how fat he is, the color of his hair, the shape of his nose, and the kind of clothes he is wearing. In a later unit you will learn more about how we see.

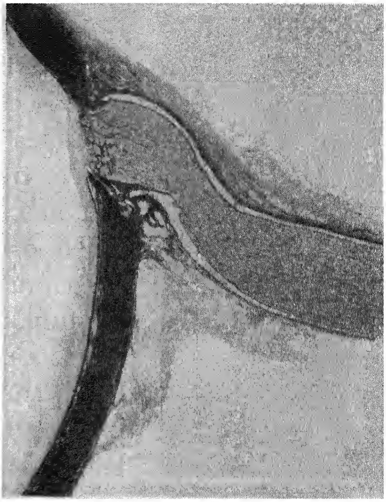


FIG. 11. Eye of a rabbit, showing the nerve from the eye to the brain (©General Biological Supply House)

The eye is what we call a *sense organ*. We speak of seeing as the *sense* of sight. At the back of the eye is a thin layer of material that is affected by light. When light falls upon it, a chemical change of some kind takes place. As a result, a nerve is *stimulated*, an *impulse*, or message, is sent along this nerve to the brain, and we see.

Because a sense organ such as the eye is sensitive to

light, we say that light is a *stimulus.* A stimulus is anything that causes a response in a living thing. Each kind of sense organ is sensitive to but one kind of stimulus. The ear, for example, is stimulated by sounds that come through the air. In the nose are the sense organs of smell. They are stimulated by tiny particles of materials that pass through the air, enter the nose, and touch the sense organs. The stimulus in this case is a chemical stimulus, because the stimulus comes from particles of a material of some kind. Taste, too, is a chemical stimulus.

FIG. 12. There is no question as to which sense organ is at work here. (Photo by Anne Shriber)

You can see now that each of the sense organs is sensitive to (that is, is stimulated by) a certain kind of stimulus. Furthermore, this stimulus starts an impulse that is sent on to the brain through a nerve. In seeing, hearing, and smelling, something always travels from the object to the sense organ. In seeing, light travels from the object to the eye. In hearing, sound travels from the object to the ear. In smelling, tiny particles of the object travel to the nose. Because of this, these three sense organs are able to tell us much about what is going on around us.

Scattered over the skin are a large number of sense organs of another kind. Some of these are sensitive to cold, some to heat, some to pain, and some to touch. In some parts of the body these sense organs are close together, as in the finger tips. In other parts, as the back, they are much farther apart. Each kind of sense organ is

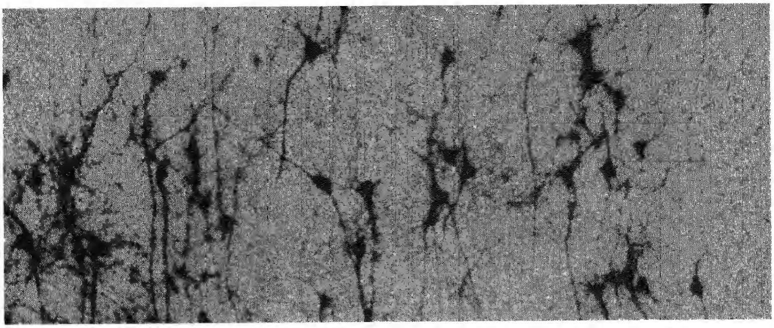


FIG. 15. There are many kinds of nerve cells in the body. This picture shows some of the nerve cells in the brain, highly magnified. (©General Biological Supply House)

reaches the ear.) The nerve carries this impulse to a certain area in the *cerebrum*, the upper part of the brain (Figure 14). This area is called the *sensory area*. The nerves from the different sense organs are connected with this part of the brain. In the sensory area is a certain part called the *auditory* (hearing) *center*. This part of the sensory area receives the impulses from the ear.

Another set of nerves now carries this impulse to another part of the cerebrum, the *association area*. The association area is the part of the brain that helps us remember. Here the impulses that come into the brain acquire a meaning. The sound impulse becomes a word, "Bob." To you "Bob" means yourself. You recognize the voice of your mother. You know that it is about six o'clock and that this is the time you usually eat. This idea is made stronger by an empty feeling in your stomach In other words, the sound of your name, the time of day, and the empty feeling in your stomach are connected with past experiences. The scientist would say that they are *associated* with similar past experiences. As a result of these associations with experiences you have had, the word "Bob" means to you that it is dinner time and that your mother is telling you to come to dinner.

The association area is connected with the *motor area*

of your brain. The motor area is the part of the brain that sends impulses to the muscles of your body. After the sound becomes meaningful to you, the association area sends a message to the motor area. The motor area sends out messages to the proper muscles. As a result, you put down your book, get up, walk into the dining-room, and sit down at the table.

Now let us take another common experience and see if we can explain what happens. Let us suppose that someone says to you, "Take this and tell me what it is." You answer immediately, "It's an orange." How did you know what the object was?

First of all, your sense organs sent impulses to the sensory area. These impulses were then sent on to the association area, where they acquired meaning. Impulses from the eye supplied you with information as to the shape, size, and color of the object. Impulses from the nose were interpreted by your brain as a certain odor. Impulses from the sense organs in your skin informed you that the object was rather soft and that its surface was not quite smooth. Impulses from the sense organs in your muscles told you something about the weight of the object.

In the association area of your brain all of this information was gathered together and connected with previous experiences. The sum of all the information you received from your sense organs was like the sum of the information you had received many times before. A long time ago you learned a word that you could use for all of this information. This word was "orange." The person to whom you were talking had also had the same experiences with this object, and he also uses the word "orange" to stand for his experiences with the object. So when you said, "It's an orange," he knew what you meant.

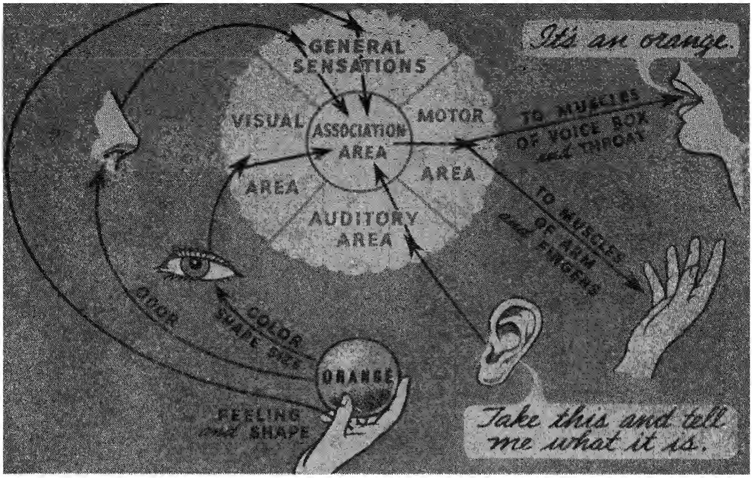


FIG. 16. This diagram will help you understand what happens when messages go to the brain from the various sense organs. Be sure that you can explain everything in this diagram.

Now let us see what you have learned from the two examples of behavior that you have just read about. The cerebrum, or upper part of the brain, is divided into three areas. One area, the sensory area, receives the impulses that come from the different sense organs in the body. This area is also divided into smaller areas. One area receives impulses that come from the ear, and another receives the impulses that come from the eye. Still others receive impulses from other kinds of sense organs.

Impulses received in the sensory area are sent on to the association areas. Here the impulses from different sense organs are associated. These impulses then become meaningful when they are associated with memories of earlier experiences. In other words, you know that an object is an orange, you know what people are saying to you, and you know what you are reading. The association area is the store-house for the changes that have taken place in the nervous system because of past experiences. These past experiences make present experiences mean something to you and tell you what to do or how to behave.

If your behavior in a situation is to be some kind of movement of your body, impulses are sent on to the motor area of your brain. The motor area then sends these impulses on to the muscles, and you move your body, or some part or parts of it, in the way that you have decided.

From what you have learned about your brain, you can see why the more you know, the more likely you are to behave intelligently. You always interpret or explain a situation, an event, or an object according to your past experiences and according to what you remember about these past experiences. The more experiences you have had, the more meaningful the new situation is. For example, when you watched your first football game, you probably had little idea of what was going on. You knew that the ball had to be carried to one end of a field and that a score of six points was given whenever this happened. At times the referee would blow a whistle, pick up the ball, and move it back a few yards. You did not know why. However, at each game you attended you found out a little more about the game. If you actually played football, you accumulated a whole new set of experiences, and the game came to mean much more to you.

Do you see, now, the important reason why you go to school and study many different subjects? By reading, experimenting, and thinking in school, you have many more valuable experiences than if you spent all your time playing. There are also valuable kinds of experiences you get by playing with others, by working, by attending religious services, and in other ways.

In this problem you have been studying about the ways in which human beings behave. If you have understood what you studied, you have a better idea of why you behave as you do. For example, in one of the illustrations

FIG. 17. Look at the objects in this picture; then think about each object. What does each object mean to you? Does the object mean something to you because of what you have done or of what you have read, or both? For example, the canoe may make you think of Indians, tepees, a camping trip, a time when you were tipped over, etc. Do the objects mean different things to some of your classmates? Why?

"Bob" meant to you, "Come to dinner." We have explained why it meant this to you. Sometimes "Bob" may mean, "You are making too much noise. Be quiet." Can you figure out why "Bob" means one thing one time and something else another time? If you can, you understand what you have studied.

You have also seen that words come to stand for certain objects, situations, or events. If I say the word "iron," "summer," or "airplane," you know immediately what I am talking about. The larger your vocabulary of meaningful words is, the better you can listen, think, and speak. One of the most important things you can do in school is to learn the meanings of a large number of new words. In your thinking each new word stands for experiences you have had.

Self-Testing Exercises

1. To what part of the brain do impulses from the sense organs go? Where do they go from there? What happens in this area? How does the message finally get to the proper muscles?

2. Explain how you recognize and name objects.

3. The more you know, the more likely you are to behave intelligently. Explain why this is true.

4. Why does the sound of your name mean one thing to you one time and something else to you another time?

Problems to Solve

1. Suppose that you see your mother sitting in a chair beside an open window. Suddenly, she gets up and closes the window. Tell what you think happened and explain why she behaved as she did. What experiences have you had that caused you to give this explanation?

2. Blindfold a person and then clap two sticks together directly behind the person. Ask him to point in the direction from which the sound came. Try it several times. Can he do it? Now clap the sticks together behind, but at one side of, the person. What happens? Explain.

3. Many of the things we think we recognize by taste, we really recognize by smell. Experiment to discover whether you recognize an apple, a potato, and an onion by taste or smell.

4. Have someone name several things, one at a time. Write the experiences that come to your mind as a result of each word. Compare with what your friends put down.

HOW DO WE FORM HABITS? Can you carry on a conversation with someone when you are eating a meal or buttoning your coat? Or do you have to think about how to say each word, how to hold your fingers about a fork, and how to get a button through the buttonhole? When you learn something new, such as skating or riding a bicycle, you have to pay attention to what you are doing. After you practice for some time, the whole pro-

FIG. 18. A skilled pianist does not have to think where to put his fingers to strike the right notes. He reads the music and strikes the keys almost automatically. He has practiced until reading the music and striking the right keys have become habits with him. Therefore he can put all this attention on how fast to play, how loudly, how softly, etc. (Ellis O. Hinsey photo)

cess becomes automatic; that is, it will go on by itself with almost no attention from you.

When you learn to do something in a certain way and no longer have to pay attention to what you are doing, you have acquired a *habit*. Reading, writing, talking, swimming, eating, putting on your shoes, riding a bicycle, and many other activities of your daily life are habits. You start the activity going, and then it continues without further direct attention from you. If you have never thought about habits, you will be surprised to learn how much of your behavior is more or less automatic because of the habits you have formed. And without habits you would have little time left for doing things that are not habitual. Of course, some habits are bad. These interfere with our living or make us less pleasant companions.

The habits we have been talking about are mainly those concerned with moving the body or parts of it. You can also get into other habits: for example, the habit of being on time or late, the habit of doing your work carefully or carelessly, the habit of obeying your father and mother, or the habit of disobeying. You can develop habits for practically everything you do.

FIG. 19. This expert tennis player is not thinking about just how to hold the racket and just how to swing his arm. Such things have become habits through long practice. Therefore he can put all his attention on where he wants the ball to go and how hard he wants to hit it.

Fortunately, you can always form new habits. New habits will often help you to do things more efficiently. Also, the best way to get rid of an undesirable or bad habit is to form a new and desirable one to take the place of the bad one. You can form a new habit much more surely and quickly if you know the most effective method. First, you should be quite sure that you really want to form the new habit. Second, start the new habit with as much determination and attention as you can. Make the starting a real occasion in your own life whether others know about it or not. Third, never let yourself act contrary to your new habit until it has been well formed.

As an example, let us suppose that you have the bad habit of holding and using your knife and fork incorrectly. You will continue in this habit until you set out to

FIG. 20. These men are learning to be instructors of blind people. For many days they have to live blindfolded so that they will know exactly what problems blind people meet in getting around. During these days they develop many new habits to help themselves get along without the sense of sight. (Acme photo)

break it. To break the old habit you must form a new and stronger habit of eating in the correct way. To start with, be sure you really want to do it. Your efforts will probably be wasted if you try to change merely because your father and mother want you to do so. Give some thought to the problem and decide that you will be a more pleasing table companion for your family and your friends if you change your habit.

Second, get a good start by giving careful attention to the correct way of eating. Watch those who eat correctly. Then take a knife, fork, and food to your room and practice. Third, at every meal, even though you sometimes eat alone, be very sure to hold the knife and fork correctly. After a week or so you will find that you have formed the new habit. Soon you can forget your knife and fork. The new habit will take over the job of managing them in the proper manner. It is the same way with other habits. They can be broken by forming new habits to take their place. A set of good habits is about the most valuable possession that an individual can have.

Now that you are just starting a new year of school work, you should give some attention to your habits of

doing your school work. What kind of worker do you really want to be? How can you get to be that kind of worker? What bad habits do you have? What good habits can you form to take their places? Choose a habit that you really want to change and go to work on it. For example, choose one or more of the following ways to study and practice until it becomes a habit:

1. I shall form the habit of making a preliminary inspection of my work before I start to study to be sure that I know what to do.

2. If I do not understand the assignment, I shall ask the teacher to explain what I do not understand.

3. I shall review the previous lesson before I start on a new lesson.

4. I shall try to think of examples to illustrate the principles or ideas presented in the lessons.

5. When the teacher asks questions, I shall always answer them to myself even if I am not called upon.

6. I shall think of questions to ask about the things we are studying.

7. I shall not believe everything I hear. I shall ask questions or go to books to check up on things.

Self-Testing Exercises

1. What is a habit?
2. Why is the formation of good habits valuable to us?
3. How can you break a bad habit and form a new habit?
4. Read your answer to Introductory Exercise 3. Add other habits to your list.

Problems to Solve

1. At the beginning of a new year one often writes the preceding year's date. Explain.
2. Is it easier to form a bad habit or a good habit? Explain.
3. Tell how you have formed some new habit.

FIG. 21. The famous Seeing-Eye dogs for blind people are trained to do amazing things. They stop at curbs to be sure that traffic is clear, and will turn right, left, or go ahead, according to their owner's instructions. They will pick up objects, even as small as a dime, that their owners may drop. It takes about three months to train a Seeing-Eye dog, and the owner has to go through a month's training to learn how to use the dog. (Courtesy "The Seeing-Eye," Morristown, N. J.)

HOW DO WE THINK? If you were asked why you can behave more intelligently than a dog, an ant, or an angleworm, your answer would probably be, "I can think, and they can't." This is correct. But what do you mean when you say that you can think?

Let us watch the behavior of a dog in a certain situation. You are training the dog to pick up a stick and return it to you. One day you throw the stick over a picket fence. The distance between the slats is wide enough so that the dog squeezes through the fence and goes after the stick. He picks up the stick by the middle and attempts to return through the fence. Of course, he cannot get through with the stick in his mouth. What does he do? He runs up and down the fence looking for a wider opening; he tries to jump over; he sits on his haunches and whimpers. He tries all sorts of antics.

Finally, in picking up the stick, which he has dropped in his wild scrambles, he accidentally gets hold of it by the end. This time he is able to squeeze through the fence

with the stick in his mouth. Would you say that the dog is doing any thinking in this situation?

Before we answer the last question, let us see what you would do in the same situation. You would pick up the stick and bring it to the fence. You would see, without trying it, that the stick would not go through the slats if held horizontally in front of you. If the space between the slats were wide enough, you might squeeze through and then pull the stick after you. Or you might throw the stick over and then climb the fence yourself. You would decide what was the best thing to do; then you would do it. Your behavior in this situation would be the result of thinking. You would see what the problem is and solve it. The dog, on the other hand, would not understand what the difficulty was. He would not see why he could not carry the stick through the fence. He could not plan a way to solve the problem. He could not think as well as you can.

'IG. 22. This chimpanzee has no idea what he is doing. He is merely imitating something he has seen done. Many animals seem to like to imitate persons and other animals.

Now let us consider the behavior of a hungry ape that was placed in a cage. A banana was placed about ten feet away. Two short bamboo sticks, one smaller than the other, were placed in the cage. The smaller stick could be fitted into the hole in the larger stick. What did the ape do? First, he tried to reach the banana with his hands.

Then he picked up one of the sticks and tried to reach the banana. But the stick was too short. So he gave up for the time and played with the sticks. While playing with them, he accidentally fitted the smaller stick into the large stick. At once he poked the long stick he had made through the bars of his cage and got the banana.

This behavior is different from the behavior of the dog. The ape remembered that he could not reach the banana with one stick. When he saw the long stick that he had made, he apparently realized that this long stick might reach the banana. In other words, he actually thought out a way to get the banana. This is a case of very simple thinking. The animal actually discovered for himself how he could get what he wanted.

Of course, if you were placed in such a situation, you would immediately figure out what to do. You would see that one stick was too short, and you would not even try it. You would see at once that you needed a longer stick, and you would put the two sticks together. You can think better than the ape.

The great advantage in being able to think is this: When you have a problem, you can bring many of your past experiences to bear on the problem, and you can use these experiences to help you find a way out of your difficulty. You can "think" of different ways in which you might solve your problem, and can pick out the method that seems most likely to succeed. You can think ahead. You can plan what you are going to do. The ability to do these things makes man the most intelligent of all the animals and really makes him the ruler of the world of living things. Man can do these things because he has a marvelous brain. No other animal has a brain that can even compare with man's brain.

You behave in one way in which no other animal can behave. An animal always responds to any situation in which it finds itself. It does something to try to satisfy the immediate desires that it has. It never looks into the future to consider what it should do. If an animal is hungry, it eats. You do not always do this. For example, you have some money and you are passing a candy store. You are hungry, and you want some candy very badly. You think, "If I buy the candy, I cannot go to the movies this evening. So you do not buy the candy. In this case you refuse something you want in the present in order to have something better in the future. No other animal ever does this. Some of the higher animals can think in a very limited way, but no animal except man can plan and think in terms of the future.

FIG. 23. In this statue Auguste Rodin, great French sculptor, represented man's superiority over all other living things. He named the statue "The Thinker."

Curiously enough, even though people have this marvelous brain to direct their behavior, they do not always use it. Did you ever do something that you should not do and then when asked, "Why did you do it?" say, "I didn't think"? Probably you have. Now what did you mean when you said, "I didn't think"? You meant that you acted without considering the consequences, or what

would happen as a result of your action. "Look before you leap" is an old saying. What it really means is, "Think before you act." Many times you can save yourself and others much trouble if you will think before you act.

If you have not read "How does the scientist solve problems?" in *Science Problems, Book 1*, you should read it now. It tells you how a scientist uses his mind in making discoveries and inventions. The thinking that you do is the same kind of thinking that the scientist does. His thinking is likely to be much more accurate than yours, because he is more skillful in working out his problems. But you can learn to do more accurate thinking.

Self-Testing Exercises

1. In what ways are the behavior of a dog and the behavior of a human being different in solving a problem like getting a stick through a fence?
2. Explain how the behavior of the hungry ape was somewhat like the behavior of a man.
3. What is thinking?
4. Make a list of five situations in which you had to think today. Select one of them and tell what you did.

Problems to Solve

1. What subject in school requires the most thinking? Why?
2. Suppose you had a choice of taking a vacation either in the mountains or at the seashore. Tell how you would decide which place to go. Would this be thinking?
3. Does memorizing a poem require thinking? Explain your answer.
4. Does adding a column of figures require thinking? Does solving an arithmetic problem require thinking? What is the difference between adding a column of figures and solving an arithmetic problem?
5. Describe a situation in which you decided what to do on the basis of the future instead of the present.

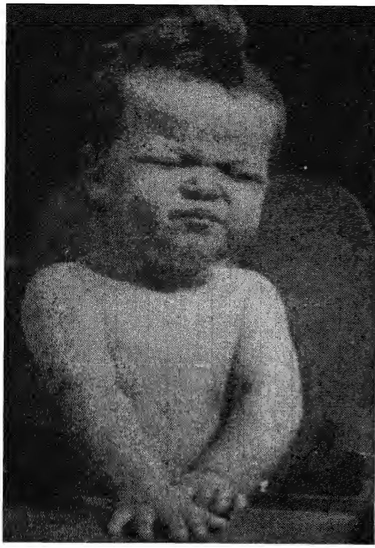


FIG. 24. Quite disgusted with everything (Black Box Studios)

FIG. 25. Life looks pretty blue to this little lady.

HOW DO EMOTIONS AND PREJUDICES INFLUENCE OUR BEHAVIOR? When you have been angry, have you ever done something for which you were sorry afterwards? If not, you are probably the only person in the world who has not done so. Unfortunately, we do many things that are not the result of careful, deliberate thinking. Something happens that we do not like, and, if we do not guard ourselves, we say or do something that we would never say or do if we had first done a little thinking. In such cases we are letting our emotions govern what we do.

Some people have what is called an ungovernable temper. That is, they get mad, "fly off the handle," and cause a commotion when anything displeases them. We can understand people with bad tempers when we understand how these people got that way. Young babies have only one way to let their wants be known. They have to kick or scream because they have not yet learned to talk. They soon learn that the louder they yell, the more attention they are likely to get. Some parents spoil the baby

FIG. 26. "I wonder what this thing is." (Black Box Studios)

FIG. 27. "I never felt better in my life!" she seems to be saying.

by giving it everything it wants whenever it "puts on a show." The baby soon learns that this is true; so he adopts this as a method of behavior to get what he wants. If he is not corrected, this behavior becomes a habit. Of course, as we grow older, we learn that not all of our wants are immediately satisfied. Some of them are never satisfied. But the habit of flying into a rage whenever anything happens that we do not like still sticks with us, even though it does not work the way it did when we were babies.

A person with an ungovernable temper is simply a person who has never grown up. He is still at the baby stage of learning so far as controlling his emotions is concerned. He has to break this habit, or he will never learn to get along with the people with whom he has to live. Many very intelligent people have made miserable failures of their lives and have also spoiled the lives of other people because they have never learned to control their emotions. Perhaps you have heard of the mother who was trying to cure her son of fighting. She told him to count to one hundred before he started to fight. This is not bad advice. By the time a person counts to one hundred, the first anger has usually passed away, and he is less likely to want to fight.

FIG. 28. Something certainly has this boy upset. Perhaps it is his stomach, or maybe he is having trouble of some kind. Did you ever feel the way he looks? (Carl Berger photo)

There is another thing that you ought to know about emotions. Sometimes everything seems to go wrong for us, and we feel "blue" and discouraged. We are likely to do things and say things under these circumstances that we would never do or say if we "felt right." At other times we feel gay and happy. Everything seems "rosy." This is perfectly natural. Everybody feels different at different times. *Psychologists* tell us that people go through regular cycles of "ups" and "downs." Every few days, weeks, or months a person will have a spell of being "downhearted." The cycles seem to be different for different people. Poor health may also make us "downhearted." In what we do we ought to recognize whether we are feeling "up" or "down" and behave accordingly. Important decisions made in either of these moods, especially when we are discouraged, are likely to be wrong.

Scientists do not know very much about emotions. They do know that emotions have a very great effect upon our behavior. The important thing for us to know about them is that if we let our emotions govern what we do most of the time, we are likely to behave foolishly. In making decisions you should try to determine whether your decision is based on sound thinking or whether it is merely emotional in character.

Then, too, each one of us has prejudices that affect our behavior. Did you ever meet someone for the first time and immediately dislike that person before he even said a word? The explanation of this goes back into your earlier experiences. For example, suppose the new person's name is Harold. Sometime in your past experience you knew a boy named Harold who teased or bullied you, and you disliked him very much. When you meet a new person named Harold, without knowing it you associate your feeling for the Harold you once knew with this new Harold. In the same way, the shape of the nose or other features of a person may remind you of someone you once knew and disliked, and you attach this dislike to the new person. You can guard yourself against prejudices of this kind if you will make it a habit not to form an opinion of a person until you know more about him.

We also have prejudices about many other things. Perhaps you are an ardent Democrat or Republican. Why? The chances are that you are the one or the other because your father or mother is. You will not even listen when someone tries to tell you that the other party is the better one. Why not? Because you are prejudiced. Actually, if you were asked to write an essay on "Why I Am a Republican" or "Why I Am a Democrat," you could not do it. You do not know what each party stands for. And if you are prejudiced, you will never find out. The only way to keep from becoming prejudiced is to keep your mind open. Do not form opinions too hastily, and do not hold them so strongly that you are unwilling to give them up in the face of new facts. Listen to others who do not agree with your opinions. If their reasoning is good, better than yours, be willing to change the opinion that you had.

It is very important to know that we are often prej-

FIG. 29. This speaker has his audience quite excited. He may be right, or he may be wrong, but he is probably appealing strongly to their emotions and prejudices. People in crowds are easily excited, frightened, made angry, and in other ways influenced. Psychologists tell us that crowds of people can be made to do things that an individual person or two or three people would never do. (Acme photo)

udiced because the people with whom we associate are prejudiced. This influence is especially important while we are young children, even before we start to school. In our relations with other people we must remember that they have grown up in contact with different attitudes and prejudices than ours. We will be more tolerant of their feelings when we understand how they "got that way."

Another important fact we should know about prejudices is the use that some organizations are making of our tendency to have prejudices. They write newspaper articles, publish advertisements, and start rumors to create prejudice in our minds. *Often they do this so that they can make more money or have more power. We need* constantly to be on the lookout for prejudices that are created in this way for selfish purposes.

Human behavior is a very complex thing. It is almost

impossible to tell why a person acts in a certain way when certain things happen to him. Habits, careful thinking, prejudices, and emotions all have a part. The more you can make your behavior depend on your reason, the more intelligent your behavior will be.

Self-Testing Exercises

1. What is the difference between behavior that is ruled by the emotions and behavior that is ruled by reason?
2. Describe a situation in which your actions were governed by your emotions rather than by reason.

Problems to Solve

1. Describe as well as you can how you feel when you are sorry, glad, afraid, angry, happy, disgusted, and annoyed.
2. Make a list of things that you do not like. Do you have reasons for not liking these things, or is your dislike based on prejudice?
3. What changes do emotions cause in your body? Think of times when you have been influenced by a strong emotion. Watch others under similar circumstances. How are the breathing, color of skin, rate of heart beat, and strength changed?
4. Is prejudice ever a good thing to have? This would be a good topic for debate in your class or your science club.
5. Does the same situation always cause the same emotion? Give examples to support your answer.

HOW DOES ALCOHOL AFFECT BEHAVIOR? You have probably seen the safety bulletins issued by automobile or insurance companies that show how long it takes to stop a car when it is going at different speeds. One of the terms used in these bulletins is *reaction time.* Let us see what this term means.

To a person who has driven a car for a long time, the shifting of gears and the application of brakes are habits. The driver does not need to think about what he does.

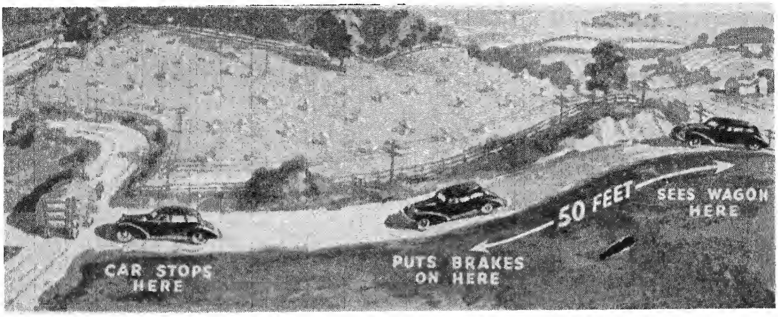


FIG. 30. This picture will help you understand what is meant by reaction time. Be sure that you can explain it and Figure 31.

If another car or a person suddenly looms up in front of him, he automatically throws on the brakes. Now, of course, it takes the person a brief second of time to act after he sees the object. The time that it takes for him to react to the stimulus is called his reaction time. This time varies for different people, but for the average trained driver it is about three fourths of a second.

You can see that a person's reaction time is very important in determining how quickly he can stop a car. Experiments have shown that alcohol makes a person's reaction time slower. In other words, it takes a second or more for an alcoholic person to react. In the meantime, the car is moving forward. A bad accident may take place because the car moved fifteen feet farther before the driver could put on the brakes. A very large percentage of the accidents that occur at night are a direct result of the effect of alcohol upon the nervous system.

Alcohol also affects one's judgment. People say and do many things that they would not say or do under normal circumstances. Alcohol weakens their sense of right and wrong, their control over their emotions, and their sense of the consequences of their actions. In other words, they

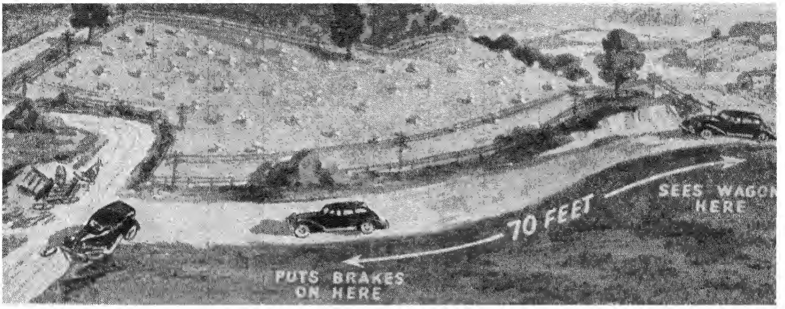


FIG. 31. This picture shows how alcohol may cause an accident by slowing up the driver's reaction time.

do not think as correctly or act as sensibly as they do without alcohol. This happens because alcohol paralyzes or dulls the higher centers of the brain that control what we do.

Self-Testing Exercises

1. Why is a person's reaction time a very important part of his behavior?
2. How does alcohol affect a person's behavior?

Problems to Solve

1. Make a list of situations in which a slow reaction time would be disadvantageous.
2. Describe a situation in which you have seen someone under the influence of alcohol. What did this person do that he would not ordinarily do?
3. In what games is a short reaction time helpful? Why?
4. Is alcohol ever a useful substance in the human body? Find out what doctors think about this problem and report to your class.
5. What kind of behavior is needed to drive an automobile most successfully? Work out a list of characteristics of a good driver. What habits are important? When is the ability to think important?

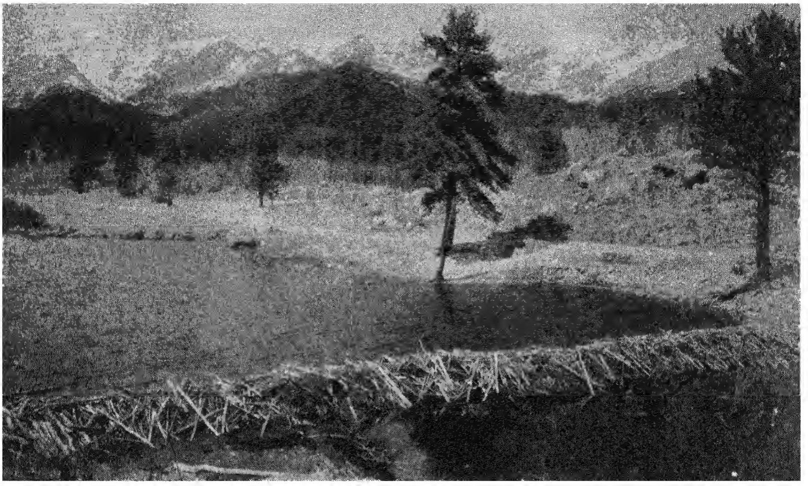


FIG. 32. Three hundred years ago in our country hunters and trappers found beavers building dams like this, and beavers are still building them in exactly the same way. Of course, nobody knows how or when they learned to do so, but it probably took place bit by bit and by accident through hundreds and hundreds of years. They could not "think out" how to build such homes. (Francis photo)

Problem 2:
HOW DO ANIMALS BEHAVE?

WHAT IS TRIAL-AND-ERROR BEHAVIOR? Now that you understand a little more about how you yourself behave, you can understand more easily how other animals behave. You will find, too, that a study of animal behavior will make you understand yourself still better. In studying the behavior of animals, you will first read about a situation in which an animal is placed and see what the animal does.

We will start with a study of a very simple animal, the paramecium. The paramecium is a tiny one-celled animal that swims by means of many tiny moving hairs called *cilia*. It has no eyes, ears, or nose to tell it what is going on around it. It has no brain to guide or direct its behavior. It is about as "dumb" an animal as you can find. But let us follow a paramecium around as it swims through the water and see what it does. Here it goes. Right ahead of it

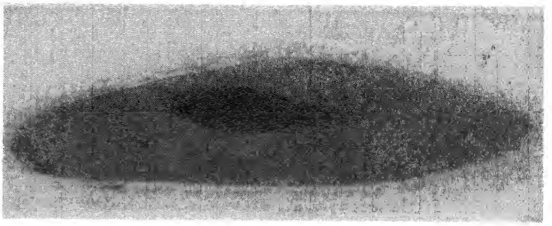


FIG. 33. A paramecium magnified about 260 times. Around the edges are the cilia. (©General Biological Supply House)

is a hard, smooth object in the water. If it keeps on in the same direction, it will surely bump into it. And so it does. This seems to be very foolish behavior, but there is no way for the paramecium to know that the object is there.

Now let us see what the little animal does. It backs up. The cilia that have been driving it forward change the direction of their strokes so that they force the animal backward instead of forward. Now the tiny animal is turning to one side so that it will head in another direction. Then the cilia take up their forward stroke again, and away the animal goes. If it runs into another hard object, it does exactly the same thing again. This is all that it can do. Scientists call this group of movements an *avoiding reaction.*

The paramecium also makes this avoiding reaction in response to other kinds of stimuli. If one side of the drop of liquid in which the paramecium is living is heated, or a strong light is sent through it, or it is cooled, or an irritating chemical is placed in it, the paramecium will stop, back up, turn to one side, and start in a new direction to avoid the unwelcome stimulus. This avoiding reaction enables the animal to find and stay in the part of its water home that is most favorable to it.

If the animal runs into a very small particle or an object with a soft surface, it usually stops swimming and starts the cilia around its mouth moving. These cilia

draw in a constant stream of water containing small particles. Many of these small particles are food for the animal. Curiously enough, if tiny particles of carmine (a red coloring material) are placed in the drop, the paramecium will take these into its body, even though they are not food. Apparently the animal cannot tell what is food and what is not food. Experiments have shown, however, that after a time the paramecium will refuse to accept carmine particles.

The paramecium has only one kind of behavior. Scientists call this type of behavior *trial and error*. Let us see what this means. The paramecium starts off in a certain direction. It bumps against something or comes into an unfavorable region. It backs up and starts off in another direction. It changes its direction constantly, so that it stays in the place most favorable to it. In other words, it finds the most favorable place by moving first in one direction and then in another, until it finds the best direction to go.

The behavior of the paramecium is trial-and-error behavior of the simplest kind. The paramecium can make only four responses. It can either go forward, stop, back up, or turn to one side and go forward again. Behavior of this kind in such a simple animal does not teach the animal anything. There is nothing else the animal can do. While the behavior of the paramecium is very simple, it is sufficient for living the kind of life that the animal lives. A man who behaved only by trial and error would have a hard time getting along in the kind of world that we live in. A paramecium can get along all right if it can get food and oxygen from the water it lives in, and if it can stay out of places where conditions are such that it might be killed. These things, as you have seen, the

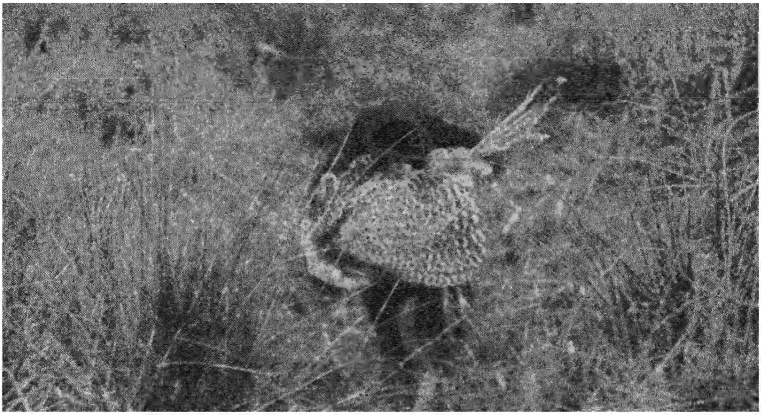


FIG. 34. People who train dogs for hunting could tell you many interesting things about how animals learn. A dog or a horse can be very easily spoiled if the trainer and the owner do not understand how animals behave. (Acme photo)

animal can do. The behavior of the paramecium is really very well fitted to meet the conditions of its surroundings. The animal does not have to be able to learn, because it can already do the things that are necessary to keep it alive.

You will see, however, that in more complex animals trial-and-error behavior is a way of learning. Suppose that we put a hungry cat in a cage. Just outside the cage we put some food. We fasten the door of the cage in such a way that it can be opened by pulling down on a loop of cord in the cage. Of course the cat does not know this. What does it do? It is hungry, and it wants to get out of the cage and get the food. It tries many ways of escape. It tries to squeeze through the bars; it thrusts its paws through the bars; it claws at the box; it paces up and down. It does the same things over and over again. Finally, by accident the cat happens to pull the string, and the door flies up so that it can get out.

You can see that this is trial-and-error behavior, too. The cat made all the movements that it could and kept them up until one of them happened to be successful. It is the same kind of behavior as that of the paramecium.

The cat, however, is more likely to be successful in getting what it wants by trial and error, because there are so many more things that it can do.

The paramecium does not learn anything from its behavior. Is this also true of the cat? You do not have to guess the answer, because it has already been solved by experiment. The experiment was performed by keeping a record of the time it took the cat to get out of the cage. On the first attempt the cat required 180 seconds to get out of the cage. After twenty-four trials the cat got out in five seconds. In other words, the cat had learned how to open the cage.

Now let us see how the cat learned. When it was put back in the cage after the first attempt, it went through the same set of movements it did in the first place, but it did not do them so many times. Finally, as in the first attempt, the cat happened to pull the loop, and the door opened. Each time the experiment was tried, the cat made fewer and fewer of the movements that were of no value. Finally it eliminated all of the useless movements and immediately pulled the loop. It had learned how to get out of the cage.

When an animal learns by trial and error, it simply makes every possible movement it can. One of the movements happens to be successful. Still the animal has no idea of how to open the cage. It does not see that pulling the loop opens the door. Learning by trial and error is a simple matter of eliminating movements that bring no results. This goes on until all of the useless movements are discarded. This is the only way that an animal such as a cat can behave. A cat cannot understand how a catch on a door works. All that it can do is to keep on trying until, by a lucky accident, it is successful.

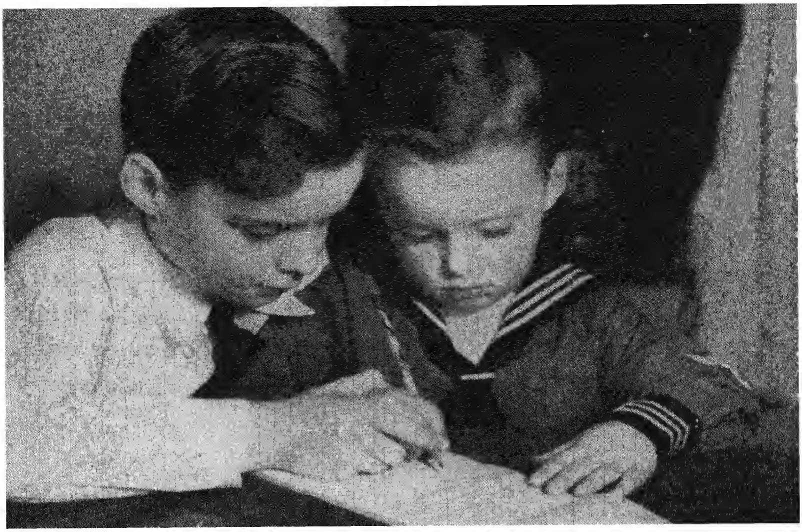


FIG. 35. If you have a young brother or sister who is learning to write, watch what he does. You will find that he wiggles his legs, frowns, and moves his body from side to side in his effort to make his fingers behave. All these movements are useless; they do not help in writing. Through practice, however, the child eliminates the useless movements, and finally only his arm and fingers move when he is writing. (Ewing Galloway photo)

You must not feel too superior to the paramecium and the cat. Some of your behavior is trial and error, too. Learning to skate, swim, dance, or write is partly trial-and-error learning. A child learns to write in very much the same way that the cat learns to open the cage. The child's goal is to make a letter like the one he sees in his book or on the board. It takes a long time before the muscles of the fingers and arm will work in just the proper order to guide the pencil in making a good letter.

We also use trial-and-error behavior in many of our more complex activities. When you make a kite, you have to guess about the correct length to make the tail. You add about what you think is right, and then you fly your kite. If it does not fly well, you change the length of the tail. You try it again, and you may still find it necessary

to add or take off some of the tail. Of course, this kind of trial-and-error behavior is much more intelligent than that of the paramecium or the cat. You know what it is you are trying to do. You figure out that the reason the kite does not fly well is that the tail is not the right length. This is real thinking. The trial-and-error behavior comes in when you try different lengths of tail.

Self-Testing Exercises

1. What is trial-and-error behavior?
2. Trial-and-error behavior does not result in learning in the case of the paramecium. Why not?
3. What is the difference between trial-and-error behavior and thinking?
4. How does the trial-and-error behavior of the cat in the cage result in learning? How do you know that the cat did not solve the problem by thinking?
5. State an example of your own to illustrate trial-and-error learning in yourself.

Problems to Solve

1. Explain how you learned to swim. What kind of behavior was it? After you learned to swim, what kind of behavior was it?
2. Explain how your learning to ride a bicycle is different from a baby's learning how to walk.

WHAT IS A REFLEX ACT? If you sit on a chair with your legs crossed and strike your leg with the edge of your hand just below the knee cap, a curious thing will happen: Your leg will kick forward. This is an action over which you have no control. The movement of your leg is a response to the blow on your leg, and it is *involuntary*. Do you know what involuntary means? If I decide to raise my hand to my eyes, an impulse passes from the motor center down to the appropriate muscles, and up

FIG. [illegible]. This little fellow looks as if he might be responding to the stimulus of a mosquito bite or a fly bite. Notice how his toes are spread apart on one foot and curled up on the other. (Black Box Studios)

goes my hand. This is a *voluntary action*. I willed that it should happen. An involuntary action is one that takes place without your willing it to take place. An involuntary act of your leg, such as we have just described, is called a *reflex act*.

You have probably noticed in a flashlight photograph of a crowd of people that many of the people apparently have their eyes closed. This is another reflex act. When your eyes are suddenly illuminated with a glare of light, you always wink. The action is involuntary; it will occur in spite of your efforts to prevent it. Let us take another example of a reflex act. Suppose that you accidentally touch a hot stove. Immediately your hand will be jerked away. This happens before you feel the pain. The impulse travels from the pain-sensitive organs in the skin to the spinal cord and then right back to the correct muscles that pull your hand away. You have no control over this, because the message goes to the muscles before you are conscious of the pain.

FIGS. 37A and B. Yawning and sneezing are both reflex acts. Sneezing is a response to irritation of the nasal passages. Scientists are not sure why it is that we yawn when we are tired. (Kaufman and Fabry photos)

A reflex act is not learned; it is an *inherited* type of response. It is a purely mechanical response; that is, it is like a machine in its action. If the lever of the machine is pulled, a certain thing happens. This certain thing always happens when the lever is pulled. A reflex, like a machine, is set in operation whenever there is the proper stimulus.

From what you have already learned about reflex actions, you can see that they go on without the thinking part of the brain. In the spinal cord and in the lower parts of the brain (*medulla* and *cerebellum* in Figure 14) are a number of reflex centers. Messages come to these centers from sense organs and are immediately sent out to a muscle or a gland that does something in response to the message. Later messages often go to the sensory area and association area to tell us what has happened.

A very large part of animal behavior can be explained by reflexes. A stimulus acts upon some part of the animal, and there is an immediate response. This response often acts as a stimulus to set off another response, and this in turn sets off another response. The entire behavior is thus purely automatic. The animal does not know why it is

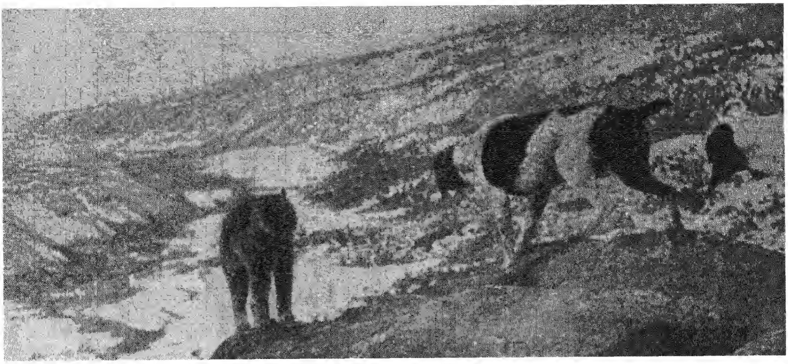


FIG. 38. Have you ever seen the hair on a dog's back stand up when it saw a cat? Sometimes your own hair feels as if it were standing up when you are frightened. This is a reflex act.

behaving in the way that it does, and it has no control over what is happening.

Much of the control of our own bodies as well as that of animals' bodies is managed by reflex actions. For example, swallowing food is a reflex act. The food first reaches the top of the esophagus, and the upper ring of muscles contracts and pushes the food down into the tube. Then these muscles relax, and a new set of muscles above the food contract and drive the food down still further. We are not conscious of this and have no control over it. Once the series of reflex acts starts, they keep on until the food is in the stomach. Other activities controlled by reflexes are breathing, the rate of heart beat, coughing, sneezing, secretion of digestive juices, sweating, and regulation of body temperature. Without reflex actions we would probably forget to do some of the things that keep us alive. And if we had to remember, we would have no time for other activities.

Curiously enough, the reflex acts of animals can be used for teaching them tricks. To understand how this is done, you will need to know about an experiment performed by a great Russian scientist named Ivan Pavlov. Did you ever hear someone say, "My mouth waters"? When

you are hungry, the sight of food acts as a stimulus to start the salivary glands pouring saliva into your mouth. This same thing happens in a dog. The sight or smell of meat will start the flow of saliva. Pavlov showed meat to a dog and at the same time rang a bell. He did this many times, and finally he found that saliva would flow in response to the ringing of the bell alone. This is something, of course, that would not ordinarily happen.

FIG. 39. Teaching a dog to bark for his food is a good example of both conditioned reflex and association of ideas.

Now let us see if we can explain this. First of all, we have the stimulus—the sight of food—which brings forth the response—the flow of saliva. Now when the food is shown and the bell is rung at the same time, the two stimuli are connected or associated with the same response. Finally the response becomes associated with the ringing of the bell as well as with the sight of food. So the ringing of the bell acts as a stimulus to the flow of saliva. This kind of response is called a *conditioned reflex*. A new stimulus, in this case the bell, has been connected with an old response—the flow of saliva.

Animal trainers use the conditioned reflex to teach animals how to do tricks. For example, if a piece of meat is held in the hand, a dog will stand up and try to get it. If at the same time the trainer says, "Stand up," the

command will become associated with the act of standing up in the same way that the bell became associated with the flow of saliva. Finally it is only necessary to say "Stand up," and the dog will respond. Many of the things an animal does when it seems to be thinking can be explained by conditioned reflexes. Since the animal now responds differently, we may say that it has learned. A great deal of animal learning of this kind takes place in the everyday life of the animal as it grows from infancy to adulthood, and even all during its life.

Self-Testing Exercises

1. What is the difference between a voluntary act and an involuntary act?
2. What is a reflex act? List some of your own reflexes.
3. Why are reflex acts of value to man?
4. Explain how an animal may learn by a conditioned reflex.
5. What is the difference between a reflex act and trial-and-error behavior?

Problems to Solve

1. Suppose that every time you spoke to your dog, you slapped him. What would happen?
2. Suppose that every time your dog jumped up on a chair or table, you slapped him. What would happen?
3. When horse-drawn fire-engines were replaced by motor-driven engines, the horses were often sold to farmers. Suppose that a farmer drove such a horse to town, and the fire bell began to ring. What do you think the horse would do? Explain.
4. Have someone stand near a window and face the light. Cover one of his eyes with some dark object. Then uncover the eye and notice the change in the size of the pupil of the eye. Have the person look at something far away and then at something near. How does the size of the pupil change? What type of behavior is this change in the eye?

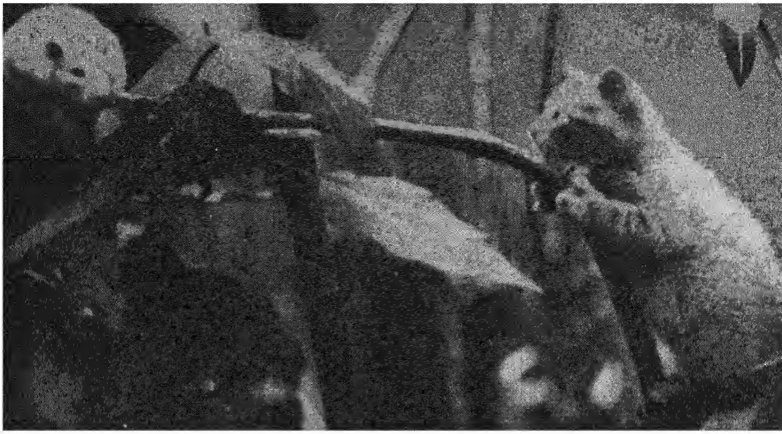


FIG. 40. This kitten is acting instinctively when it tries to capture the white mouse. Some animal mothers seem to teach their young how to capture food, but the young would instinctively get food exactly as their parents did, even without such teaching. By trial and error, as they grew older, they would become better hunters.

WHAT IS INSTINCTIVE BEHAVIOR? When you see the marvelous nests built by insects or the beautiful honeycombs made by bees, you may well wonder how these animals learned to build in such a fashion. Curiously enough, all insects of the same species build exactly alike. They build the same kind of nest and use the same kinds of materials as their parents did. Even when they are hatched from eggs and kept separated from others of the same species, they build exactly the same kind of nest. They have never seen a nest; no one teaches them how to build a nest. Still, they build nests just like the ones their parents built. Behavior of this kind is called *instinctive behavior*, or *instinct*. It is a kind of behavior that the animal inherits from its parents. It does not have to be learned during the lifetime of the animal. Scientists do not know how this takes place. They simply know that it does take place. It is unlearned behavior.

Let us examine a type of instinctive behavior shown by the digger wasp. When this wasp is ready to lay its eggs, it starts looking for a caterpillar. When a caterpillar

FIG. 41. A digger wasp dragging another insect, much larger than itself, toward its burrow (L. W. Brownell photo)

is found, the wasp pounces upon it and stings it. The poison from the sting paralyzes the caterpillar so that it cannot move. The wasp then digs a tunnel in the ground and stores the caterpillar at the bottom of it. She then lays eggs in the body of the caterpillar and fills the tunnel with dirt. In this way a supply of food is provided for the young wasps when they hatch.

Charles Ferton, a French scientist, tried an experiment with the wasp. While the wasp was filling the tunnel with dirt, he placed another paralyzed caterpillar close by. When the wasp finished the tunnel, she found this caterpillar. This acted as a stimulus to dig again; so she immediately began to reopen the tunnel. When she got down to the bottom of the tunnel, she found the caterpillar that she had buried. The sight of this caterpillar set off the response of egg-laying again, although there were no more eggs to lay. Then she filled up the tunnel, and once again she saw the caterpillar near the entrance. She immediately began to reopen the tunnel again. She kept up this same series of activities as long as she was observed.

You would not call the behavior of the digger wasp very intelligent, would you? As a matter of fact, the whole

process was instinctive. There was no intelligence involved in the performance of the act. The entire response was a series of acts, each act in the series setting off the next act. Actually, it was a chain of reflex acts such as was mentioned on page 46, and each act was inherited. The wasp inherited this instinctive response. It had no idea what it was doing. It did not think out the idea of placing caterpillars in the nest for its young. It had no idea of the result of all that it was doing. It did not even know that it was providing food for its young. Behavior like this is not learned by the animal. It is inherited from its parents.

FIG. 42. Find out how and why bees "swarm" like this. Swarming is an interesting example of instinctive behavior. (L. W. Brownell photo)

Instinctive acts are inherited in the same way as reflex acts. They differ in this way: A reflex act is a response to a particular stimulus. The response may be the contraction of a certain muscle or the production of a juice by a gland. An instinct is a response to some general situation to which the whole animal responds, not just some particular muscle or gland. The response includes a whole series of reflex acts.

Insects are not the only animals that inherit instincts. Birds build certain kinds of nests because of the instincts that they inherit. Spiders spin certain kinds of webs.

Salmon migrate from the ocean to the river in which they were hatched to lay their eggs. Birds migrate in autumn and spring. Much of the behavior of lower animals is instinctive behavior. Even some of the behavior of man is thought to be instinctive.

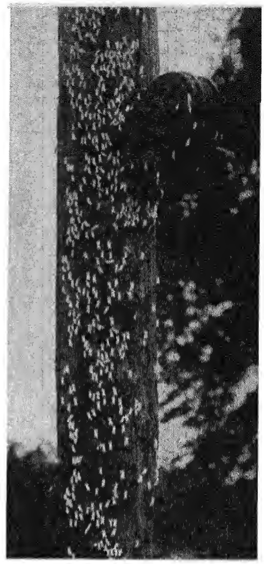


FIG. 43. Many kinds of insects are attracted by light. These are brown-tail moths on an electric light pole.

In lower animals, such as the insects, instinctive behavior cannot be changed. The animal cannot substitute a new method of behavior for instinctive behavior. In some of the higher animals instinctive behavior can be changed to some extent. The animal can be made to respond in a new way. An animal that inherits an automatic kind of behavior, such as an instinct, profits greatly from it in some ways. The animal can do nearly all the things it needs to do without learning to do them. When you think of the many hours you spent in learning to spell and to do arithmetic problems, you can see how fine it would be if you were to inherit the ability to do these things. Then you could spend your time playing ball or doing many other things that you do not have time for now.

There is, however, another side of the story. Animals that inherit most of their behavior ready-made cannot learn to behave intelligently. They cannot think or plan things. If they find themselves in an unfamiliar situation, they cannot change their behavior to fit the situation. To be able to behave intelligently, an animal needs a complex

nervous system. That is, it needs a nervous system with sense organs that respond to stimuli and thus let the animal know what is going on around it. The animal also needs nerves to carry impulses and association areas in the brain to make the impulses mean something. These lower animals cannot behave intelligently because they do not have these parts in their nervous systems. They are, therefore, fortunate that they have inherited instincts to do practically everything that they need to do to get along in life.

In *Science Problems, Book 1*, you studied a problem, "How do social animals help each other?" In this problem you saw how insects divided up the work among the members of the colony. You can see now that this was just instinctive behavior. The insects had no idea what they were doing. They inherited this kind of behavior from their parents.

Self-Testing Exercises

1. What are the characteristics of instinctive behavior?

2. Explain how an instinct may be a series of reflex acts. Would this explain the behavior of the digger wasp? How?

3. How are instincts of value to animals?

4. Why is an animal whose behavior is practically all instinctive less able to adapt itself to its environment?

5. How do we know that the social behavior of insects is instinctive behavior?

Problems to Solve

1. Make a list of kinds of instinctive behavior that are found in animals.

2. Try to think of some kind of instinctive behavior that might cause the death of an animal.

3. Would you call the hibernation of bears an instinctive response? Why?

HOW IS MEMORY USED IN BEHAVIOR? You have seen that some behavior is just trial and error. After long practice the animal finally learns to avoid doing useless things and to make correct responses. This raises a question: Can an animal learn to make a correct response without going through a long period in which he makes many useless and incorrect responses? To help answer this question, read about this experiment that scientists carried on with bees.

FIG. 44. When this trained sea lion sees the ball, the platform, and his trainer, he remembers what he has been taught to do. (Courtesy Ringling Bros.-Barnum & Bailey Circus)

First of all, the scientists wondered whether or not a bee could tell one color from another and whether it could learn to select a certain color among different colors. When scientists experiment with animals, they usually work out a system by which the animal is rewarded when it does what they want it to do. It is either not rewarded or is punished when it does what they do not want it to do. You do this, too, when you are teaching your dog a trick. You give him a piece of food or pat his head when he does what you want him to do.

And now back to the experiment. The scientists placed several glass dishes on some colored cards. They poured sugar water in the dish over one card—say the yellow card. They poured plain water in the dishes over the

other colored cards. They placed these dishes near a beehive. Then they watched to see what would happen. Soon a bee came "buzzing along." It saw the dishes of water and stopped to investigate. It sampled the water in one dish, apparently did not like it, and then tried another dish. After trying the water in several dishes, it finally reached the one with the sugar water. Then it stopped and began to feed. While the bee was feeding, it was marked with a little paint so that it could be recognized again.

When the bee got all the food it wanted, it flew into the hive. What would it do when it came back to feed again? Would it find the sugar water by trial and error, or would it remember that the dish of sugar water was over the yellow card? Other bees came, behaved like the first bee, and then left. Each bee that tried the sugar water was marked. Finally a bee came along, circled rather uncertainly over the dishes, and then flew down to the dish over the yellow card. Sure enough, this bee had a little spot of paint on it!

Was it just an accident, or had the bee really learned that the sugar water was over the yellow card? One way to be sure would be to change the dishes around and put the sugar water over a card of a different color. If, then, the bee returned and still went to the dish over the yellow card, one could be certain that the bee was responding to the color of the card and had really learned his lesson. So this was tried; and when the bee returned, it still flew to the dish over the yellow card, even though there was no sugar water in it. Of course, this experiment was tried with more than one bee; hundreds of bees were used.

What does this experiment tell us about the behavior of bees? First of all, it shows that bees can distinguish a

FIG. 45. This little terrier has been trained to follow his master into the water in a perfect dive. Notice that he has waited until he can follow his master. (Photo by Zella and Howard Hutchins)

certain color. Second, it shows that bees can learn. When the bee first visited the dishes, it sampled the water until it found the water that had sugar in it. It learned that this dish was over a yellow card. Thereafter, when it returned to feed, it picked the dish over the yellow card. To do this, the bee must have remembered which color was under the water that it liked.

But you must not get the idea that the bee said to himself, "Now let me see. What color is under the dish of sugar water? Oh, yes, I remember, yellow." This is what you or I might do, but the bee does not have a brain that permits it to think like this. It is hard to describe just what "memory" is. When a living thing has an experience, somehow or other the experience does something to the protoplasm. It leaves some sort of impression upon the protoplasm, and this impression remains. Later on, when the same experience is repeated, the living thing behaves on the basis of its previous experience. For example, when you eat something that you do not like, you remember that it was distasteful to you; and the next time it is offered to you, you refuse it.

You have probably heard the saying, "One learns from experience." This is a true saying. Almost all animals can

FIG. 46. Try to find someone who trains horses, dogs, or other animals and have him tell you how he trains them and what he knows about how animals learn. (Acme photo)

learn something from experience; that is, they can learn to change their behavior because of their memory of some former experience. You can see that at first the animal's behavior is trial and error. The bee tried dish after dish until it came to the one with the sugar water over the yellow card. But from then on its behavior was no longer trial-and-error. Somehow or other it remembered that the sugar water was over the yellow card. After it first made a correct response, it continued to make a correct response every time.

Some time ago there was a horse in Germany that was said to be able to add and multiply. By pawing with its hoof, the horse gave the correct numbers. But when scientists carried on some tests, they found that the horse could respond correctly only when he could see the trainer. If the trainer was placed behind a screen, so that the horse could hear but not see him, it could not add. The scientists found that the trainer made very slight movements which were used by the horse as a guide to the correct

number. This is a case of learning by associating a certain sign with a certain response. When you put on your coat, your dog will jump with delight. He associates this act of yours with being taken out-of-doors. A great deal of the behavior of animals can be explained on the basis of memory.

You have already seen how your own responses are based on the memory of your previous experiences. One of the reasons human beings are more intelligent than animals is that they can analyze, or break up, a situation into many single events and remember them. In other words, experiences mean more to human beings than they do to other animals.

Self-Testing Exercises

1. What does the word *association* mean?

2. Below you will find several words listed. For each word in the list write down the first word you associate with it. See if you can figure out why each word listed reminded you of the word that immediately came to your mind.

school	*elephant*	*dance*	*knife*	*book*
science	*snow*	*boat*	*girl*	*boy*

3. How did the scientists arrange their experiment so that they could be certain the bees remembered the yellow color?

Problems to Solve

1. Tell of an experience of your own in which memory played an important part in your behavior.

2. How does a dog know that a person outside a door is a stranger, even if the dog cannot see him?

3. What method of recognizing people do dogs use?

4. When you learn a poem, what method of learning do you use?

5. Find out different methods that may be used to help you remember better.

FIG. 47. This picture shows how plants can respond to the stimulus of light. They are all cone-flower plants grown in the same kind of soil. The plants at the left had continuous light day and night. The second plant had alternate hours of darkness and light. The third had alternate light and darkness every 15 minutes. The fourth plant had alternate periods of 12 hours of darkness and 12 hours of light while it was growing. (U. S. Bureau of Plant Industry)

Problem 3:

HOW DO PLANTS BEHAVE?

ON YOUR way home from school stop and look at some tree. Its roots grow deep in the ground and spread out in all directions to anchor it firmly in its place. Its solid trunk pushes its way up in the air. It seems to move only when it is blown by the wind. You would hardly believe that the tree could behave, but it, too, can and does respond to its environment. Perhaps you wonder what a tree can do. It cannot see, hear, or smell. It has neither brain nor nerves. It has no muscles to move itself or parts of its body. Yet parts of the tree do move and respond to changes that take place in its surroundings.

TO WHAT KINDS OF STIMULI DO PLANTS RESPOND? Have you ever planted seeds in a garden? If you have, you know that you can drop them into the soil in any position.

When the seeds germinate, the roots always grow down and the stems always grow up, regardless of the position of the seed. This is an interesting example of behavior. It seems that the root and stem must be responding to some stimulus. Perhaps you have guessed what this stimulus is. If you guessed that it is gravity, you are correct.

Nobody knows why gravity acts as a stimulus to plants. We do know that roots always grow down and that stems always grow up. We know, too, that the behavior of living things is always a response to some stimulus. The only stimulus that could account for the direction of growth of roots and stems is gravity. Before we accept this as the true explanation, let us try an experiment.

EXPERIMENT 1. *Can Gravity Change the Direction of Growth of the Stem and Root of a Plant?* (*a*) Grow a healthy seedling to a height of four or five inches in a flower pot. Run a knife around the edge of the pot so that the soil will not stick to the sides. Then remove plant and soil from the pot. Insert the stem through the drain hole of a large flower pot and fill the pot with rich soil. Suspend the pot and watch the growth of the stem. What happens? Make a drawing.

b) After the stem has grown upside down for a week, invert the pot, placing a board over the mouth of the pot to keep in the soil. Observe what happens during another week. Then remove the plant from the pot and examine the root. Make a drawing of the plant, showing what has happened to the stem and the root.

This experiment supplies more evidence that gravity does affect the direction in which roots and stems grow. Somehow or other it acts as a stimulus to the plant and affects the behavior of the root and stem.

Now let us arrange another experiment to observe the behavior of plant roots. You know that plants must get

food and water from the soil. Suppose we try to find out if the roots of plants can find the places in the soil that are the richest in food materials and water.

EXPERIMENT 2. *How Do Food Materials and Water in the Soil Act As Stimuli to Roots?* (*a*) Obtain a box or a large flower pot. Place a cardboard vertically in the center of the pot. Fill the pot on one side of the cardboard with rich soil and on the other side with sand. Take out the cardboard carefully and plant some soaked bean or pea seeds in the middle of the pot. Also plant a few of these seeds in the sand and a few in the rich soil. After the young plants have reached a height of two or three inches, examine the roots of the plants. What do you find?

FIG. 48. This stem grew straight out for awhile; then, under the stimulus of gravity, it turned upward.

b) Obtain a flower pot and plug the drain hole tightly with a rubber stopper or with a cork stopper and sealing wax. Place the flower pot in the middle of a box about two feet square. Fill the box around the pot with earth, and plant seeds at various points in the box. Have the earth reasonably moist when the seeds are placed in the soil. (It is usually a good plan to soak the seeds overnight before planting.) Pour water into the flower pot. Water can then enter the soil by passing through the porous walls of the pot. After the plants have grown to a height of several inches, examine the roots. What direction do they take? Do all of the roots grow in the same direction? If not, explain the difference in direction.

The experiment shows you that roots do grow toward the parts of the soil that provide the most abundant

food materials and water. We understand enough about behavior to know that the roots are acting in a purely automatic fashion. The food materials and water somehow or other act as stimuli to the roots. They respond by growing in that direction.

The response of roots to water sometimes causes us trouble. Tile pipes are usually used to carry away the waste water from houses. Some of the water may escape from the joints where two tiles meet. Roots in the vicinity of the tile will grow toward the leak. Often they actually push their way through the joint and enter the tile. The growth of the roots may completely fill the tile and stop the flow of water. Then the tile must be dug up and the roots removed. Now let us see how plants respond to light.

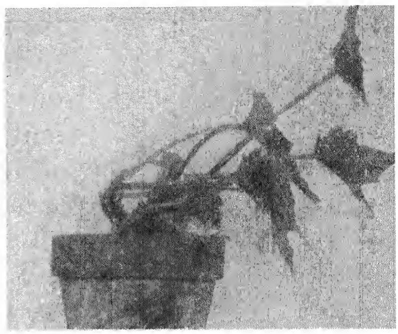


FIG. 49. All the light was shut off from one side of this plant. Notice how it grew in the direction from which the light came.

EXPERIMENT 3. *How Do Green Plants Respond to Light?* (*a*) Plant radish seeds in a pot or pan. When the plants have grown to a height of one inch or more, place the pot in a tight box that has a hole about two inches in diameter on one side. Keep the box in a light room. After two or three days remove the pot and notice the position of the stems in relation to the hole.

b) Now place the pot in a south window where it may receive sunlight, and turn the pot so that the stems will point away from the window. Observe any changes that take place.

c) Obtain a young sunflower plant or sweet clover plant. Put it in a south window. Notice the position of the stem and the crown of leaves early in the morning of a sunny day. Just before sundown again observe the plant. What changes, if any, take place?

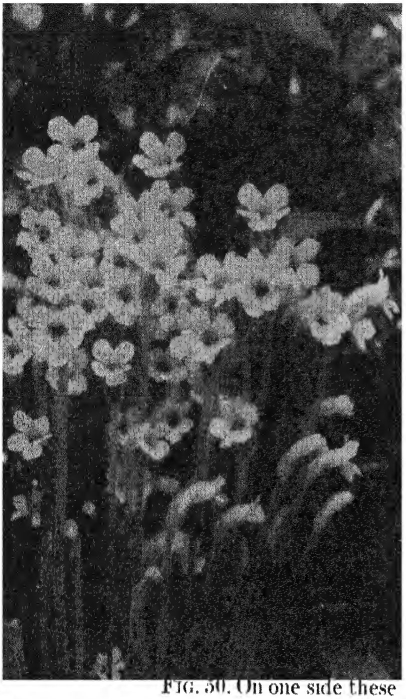


FIG. 50. On one side these flowers were shaded by weeds. Notice how they have all turned their blossoms toward the light. (L. W. Brownell photo)

These experiments show that plants respond to light. Not only does the leaf turn so that its broad surface is facing the light, but, as you saw in part *a* of the experiment, the whole plant may grow toward the light. This response of leaves to light can be seen if you will look at some vines growing on the walls of a building. The leaves are arranged in such a way that they do not overshadow one another.

Many flowers respond to light also. You can see this for yourself if there are any sunflowers in your vicinity. Each young sunflower twists on its stalk, and its face follows the sun in its journey across the sky. There is still another way in which plants respond to light. In the evening, when darkness comes, flowers such as the crocus, gentian, and water-lily close. Some flowers, such as the evening primrose and night-flowering catchfly, open as night comes. So you see that the response of flowers to light is different in different plants. Some flowers make no response at all.

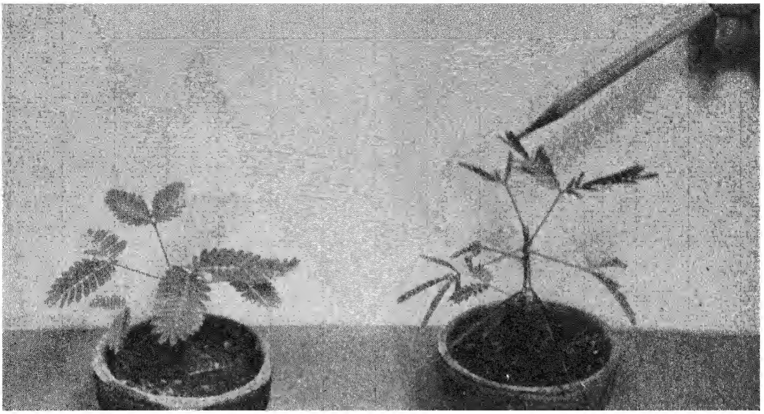


FIG. 51. How the sensitive plant responds to the stimulus of touch

Perhaps you are curious as to why light or the absence of light acts as a stimulus to some plants and not to others. Nobody knows the answer. Did you ever notice what happens to the leaves of the white-clover plant at night? They droop down and fold together when night comes; then they straighten up and spread out again when daylight comes. Scientists call the movements of flowers and leaves at night *sleep movements*. Of course, the plants are not really sleeping in the sense that we think of going to sleep. The opening and closing of flowers and the folding and spreading of leaves are responses to the stimulus of light. In some plants sleep movements are caused by another stimulus, namely, the lowering of the temperature after the sun goes down.

Curiously enough, some plants respond to touch, as Figure 51 shows and as you can see for yourself.

EXPERIMENT 4. *How Do Sensitive Plants Respond?* Obtain a sensitive plant (*Mimosa pudica*). This can be bought from a greenhouse or can easily be grown from seeds available at any seed house. Stroke a leaf lightly with your finger. What happens? Pinch the end leaflet of the plant. What happens? Does the motion follow slowly or quickly? Do the leaves regain their normal position again? Will the leaves respond a second time?

FIG. 52. This Venus's-flytrap is waiting for its prey, with its leaf open. (Hugh Spencer photo)

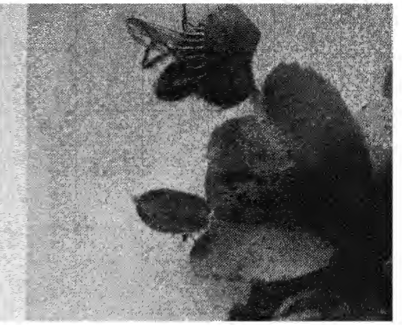


FIG. 53. A fly has wandered on to the leaf, and the leaf has closed. (Hugh Spencer photo)

Venus's-flytrap is another plant that responds to the stimulus of touch. The leaves are hinged in the middle, and there are bristles on the edges. When an insect touches a leaf, the halves close quickly together, and the insect is trapped. Digestive juices are then poured out from the leaf, and the insect is digested. Then the halves of the leaf open again, and the plant waits for another victim. You have now seen that plants respond to the stimuli of gravity, food materials, water, light, temperature, and touch. Many other examples could be given.

WHAT IS THE NATURE OF PLANT RESPONSES? Now think about the responses of plants that you have observed so that you can see more clearly just what kinds of responses are made. In Experiment 1, page 61, you found that the roots of plants grow down, and the stems grow up. If the position of the plant is changed, the roots and stems change their position, too. No matter what way the plant is turned, the roots will always grow down, and the stems will grow up. In other words, the response made by plants to the stimulus of gravity is always the same. You found that this was also true of the response of the plant to light. The leaves always turned toward the light. If the plant was turned, the leaves turned, too. These responses of plants to stimuli are called *tropisms*.

Let us see more clearly what a tropism is. In the first place, plants have no brains, nor do they have nerves of any kind. The first characteristic of this type of response is that it can be made by an organism that has no nervous system. It is thus a very simple kind of response. In fact, it is the simplest kind of response that can be made. Or we may say that it is a very simple kind of behavior. In Experiments 1, 2, and 3 you saw that some part of the plant turned in response to the stimulus. Roots turned down, grew toward water, and grew toward food materials. This is the second characteristic of a tropism. It is a turning toward or away from some stimulus.

In the third place, the plant does not have to learn how to turn. It inherits this ability from preceding generations of plants. A tropism is thus an inherited response; it does not need to be learned.

You saw that the plant or part of the plant always responds in the same way to the same stimulus. Roots respond to gravity by growing down, while stems respond to gravity by growing up. The fourth characteristic of a tropism, then, is that the plant or part of the plant always makes exactly the same kind of response. Its behavior is purely automatic.

Now let us go back to the tree we first talked about. Think of all that happened to make the tree grow the way it did. The roots grew down in response to gravity and then spread out through the soil in response to the stimuli of the food materials and water in the soil. The stem grew up in the air—a negative response to gravity. The leaves turned upon their stems in such a way as to get the greatest amount of light. The leaves drop in the fall and thus prevent the tree from losing water by evaporation through the leaves. This is necessary in the winter when

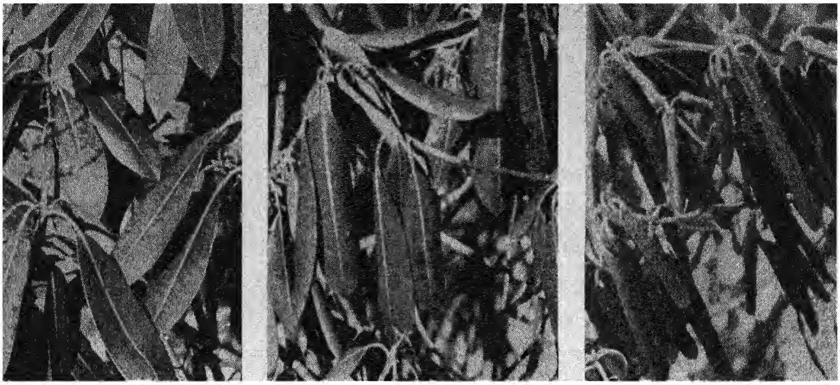


FIG. 54. The way these rhododendron leaves respond to temperature makes them almost as good as a thermometer. The leaves at the left were photographed when the temperature was above 32 degrees, those in the middle when the temperature was between 20 and 30 degrees, and those at the right when the temperature was below 20 degrees. (Photos by Herbert Wisner from *The Science Observer*)

the tree cannot get water from the soil. When the temperature rises in the spring and moisture becomes abundant, the buds swell, and new stems, leaves, and flowers are produced.

This behavior of the entire tree, as well as of its different parts, fits the tree to live in the surroundings in which it is found. Other plants behave in much the same way as the tree. They are not intelligent, but their responses to the stimuli of their environment do enable them to make the most of their surroundings.

Self-Testing Exercises

1. To what kind of stimuli do plants respond?
2. Explain what a tropism is.
3. Explain how tropisms help a plant adapt itself to its environment.

Problems to Solve

1. Read pages 60 to 68 again to find examples of the behavior of plants.
2. Think of some ways in which we make use of our knowledge of tropisms.

LOOKING BACK AT UNIT 1

1. The following statements review your understanding of the behavior of living things. Copy the statements in your note-book. Write a "C" in front of each statement that you know is correct. Write a "W" if you think the statement is wrong.

a) The word *behavior* is a name for all activities of living things.
b) Only human beings can behave.
c) Breathing is a method of behavior.
d) Plants can behave.
e) All animals can profit from the experiences that they have had.
f) The behavior of some animals is purely mechanical.
g) A horse can be taught to add numbers.
h) Some animals inherit the ability to carry on certain types of activities.
i) Some activities can be learned so that they can be performed without thinking about them.
j) The behavior of an animal depends upon the complexity of its nervous system.
k) Very young children cannot reason.
l) Man differs from other animals in that he can think better.

2. Copy the headings of each of the sub-problems in the unit. For example, the first sub-problem heading, found on page 9, is, "How do you know what is going on inside your body and around you?" Write in a few sentences the answer to each sub-problem of the unit.

3. Show in some way that you understand what each of the following words means:

association	*behavior*	*reflex act*
association area	*cerebrum*	*response*
avoiding reaction	*habit*	*sensory area*
instinctive behavior	*impulse*	*stimulus*
involuntary action	*motor area*	*thinking*
conditioned reflex	*reaction time*	*tropism*

ADDITIONAL EXERCISES

1. If you have ever had experience in teaching tricks to an animal, describe the methods you used.

2. If you are asleep and your hand is touched with a hot iron, will you jerk your hand away? Explain your action.

3. Prepare a report on "The Instinctive Behavior of Social Insects."

4. Why is it possible for a person to walk in his sleep?

5. If you have a young brother or sister, give him a pencil and paper. Watch the way he holds the pencil while making marks. Report his behavior to the class.

6. If a live frog is available, press it on both sides just behind and slightly under the forelegs. If a certain spot is touched, the frog will croak. This is an example of a reflex.

7. Obtain some live caterpillars. When they are feeding on leaves, place a small piece of paper or tinfoil on a leaf that is being eaten. What happens? Let the caterpillar continue eating, and again try your experiment. Repeat it many times. Does the caterpillar learn not to bite the paper?

8. Find out more about Ivan Pavlov's experiments with dogs.

9. Watch your dog or any other pet you may have. What responses does it make that are apparently instinctive?

10. In reference books read about Yerkes's experiments with earthworms to determine whether they can learn by experience.

11. Suspend a piece of meat by a string so that the meat is higher than your dog can jump. Place a box almost underneath the meat. Does the dog learn to use the box? If so, how does he go about it?

12. Try to learn to write your name with your left hand. You might also try learning to write your name backward. Record the time required to write your name for each attempt. Explain why this is an example of trial-and-error behavior.

13. If you want to know more about the structure of the nervous system, read *The Workshop of the Mind*, by Hallam Hawksworth.

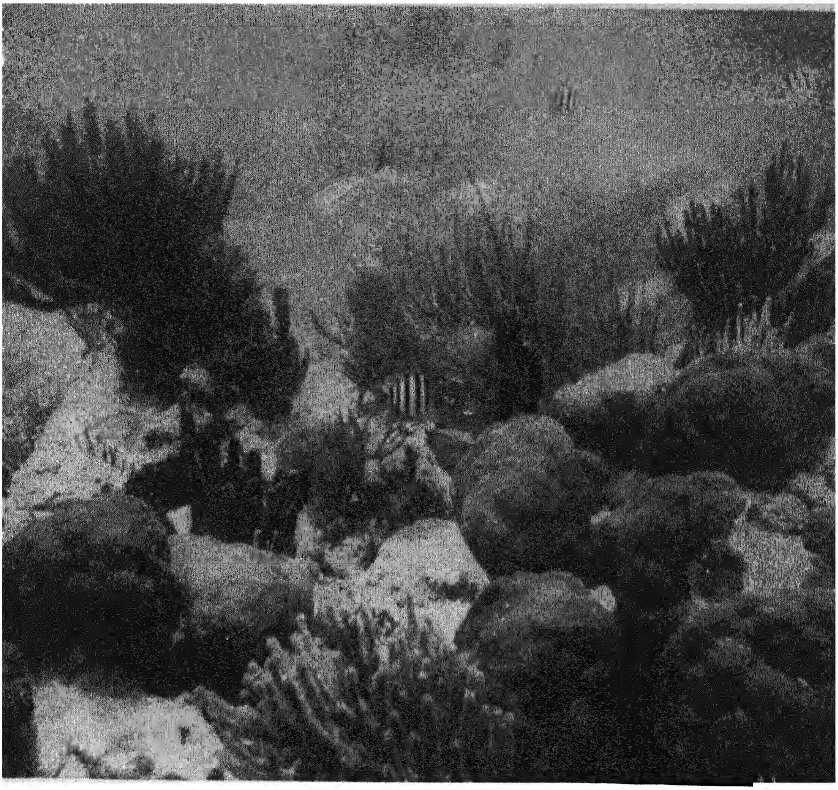


FIG. 55. In the warm, shallow waters near Bermuda you may descend twenty or so feet in a diving helmet and find yourself in a fascinating undersea garden like the one in this photograph. But this garden is filled with animals—not plants. There are pink or orange sea-anemones, purple sea whips, and red and pink corals. All these animals are called *coelenterates.* This is just one of the many groups of animals. In this unit you will learn some of the large groups into which animals and plants are classified and some of the main characteristics of each group. (Mechanical Improvements Corp. photo)

UNIT TWO

UNIT 2

HOW DO SCIENTISTS CLASSIFY LIVING THINGS?

INTRODUCTORY EXERCISES

*1. (*a*) From what you have already learned in your science study, tell what you know about how the bodies of living things are put together. Also tell what the bodies of plants and animals are made of. (*b*) In what ways are all living things alike?

*2. What kinds of one-celled plants and animals do you know about?

3. How many different kinds of animals do you know? Make a list of them.

4. How many different kinds of plants do you know? Make a list of them.

5. You probably know the names of many of the birds and trees that you see. How do you identify a bird or a tree; that is, how are you able to tell what kind of bird or tree it is?

6. How does classifying living things make it easier to learn about them?

7. In what ways is a snake different from a fish? In what ways are these two animals alike?

8. Suppose that you have the seeds of a hundred different kinds of plants. What characteristics could you use to divide the seeds into different groups? After you have thought out a plan for dividing the seeds into different groups, try to think of a way to divide each of these groups into smaller groups.

FIG. 56. One ambitious high school has organized a Biology-Taxidermy Club. This picture shows a part of their increasing collection of stuffed and mounted animals. Can you identify the pelicans, golden eagle, duck, gull, squirrel, armadillo, skunk, alligator, and fish? How do you tell these animals apart? The members of this club know a great deal about the structure of different animals. After you have studied this unit you, too, will know more about the vast animal and plant world. (Photo by Giles Studio)

LOOKING AHEAD TO UNIT 2

WHEN YOU read the title of this unit, "How Do Scientists Classify Living Things?" you probably wondered what it was about. Perhaps you thought, "Here is another one of those strange things that scientists do." But classifying plants and animals is not a strange thing to do at all. You have been classifying things all your life.

Suppose that you say to me, "I just saw an animal on a plant eating another animal." I would not have a very clear idea of what you saw. I might imagine that you saw a black-snake on an oak tree eating a young robin, or that you saw a sparrow on a morning-glory vine eating a caterpillar. I could think of many things that you might have seen. But if you tell me that you saw a bird on a tree eating an insect, I have a pretty definite idea of what you saw.

FIG. 57. A gardener might say that he had used low-growing roses as *border plants*. He might also speak of the roses, the delphiniums, and the shrubbery as *perennials*, and of the hollyhocks as *biennials*.

When you tell me the names of the groups to which the animals and the plant belong, instantly I have a picture of what you saw. If the animal is a bird, I know that it has two legs, feathers, and two wings. If the animal it is eating is an insect, I know that it is eating a small animal with six legs, three main parts to its body, and a hard covering on part of its body. If the plant is a tree, I know that it is a tall plant with leaves, bark, trunk, and branches, and that it lives year after year. When you classify the animals and the plants as belonging to certain groups, you give me a general idea of what the animals and the plant are like.

Classifying things, that is, putting together things that are alike in some ways, is an everyday activity. In the kitchen your mother puts all the cups together, all the plates together, all the glasses together, and so on. The storekeeper keeps his thread in one place, his silk goods in another place, his dresses in another place, and so on. Perhaps you have heard your father or mother talk about their garden. They speak of planting annuals, biennials,

shrubs, border plants, late-flowering plants, early-flowering plants, and so forth. The names stand for groups of plants, and people who know about gardening know what kinds of plants belong in each group.

Why do we classify things? It is the only way we have of keeping things in order. If things are in order, we know where to find them. Furthermore, when we group together things that are alike, we can talk about things more easily because we can make up a name for each group. Scientists found out long ago that they could not talk with each other about the things they had learned, and they could not tell the world what they had discovered unless they had exact names for things. They needed to know exactly what each kind of living thing is, and they needed to have a name which means that living thing and nothing else.

Does ragweed grow where you live? If you think it does not, then answer this question: Where you live, do any of these plants grow—Roman wormwood, bitter-weed, wild tansy, hayweed, hogweed, carrotwood, and stammer-wort? If any of these plants grow where you live, then ragweed grows there, too, because they are all names used for ragweed in different parts of our country.

ragweed have in your community? (Brownell photo)

Have you ever seen a flicker? Perhaps you have; perhaps you

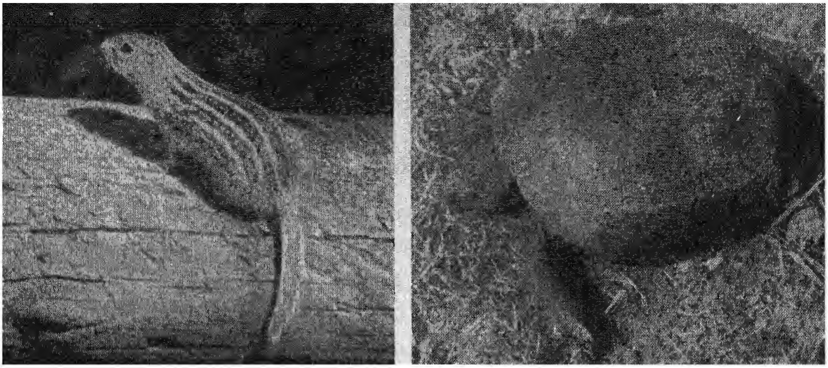


FIG. 59. Both of these animals are called "gophers" in different places. One is a striped gopher, or striped ground squirrel. The other is a gopher turtle. (Photos by R. W. Dawson and L. W. Brownell)

have not. But if you have ever seen a golden-winged woodpecker, a high-hole, or a yellow hammer, you have seen a flicker. All these names stand for the same bird.

Do you know what a gopher is? If you live in Minnesota, you are probably saying to yourself, "Sure, I know what a gopher is. It is something like a squirrel, but it lives in the ground. It is grayish-brown in color and scampers along the ground with its tail in the air." But if you went to Florida, you would get the surprise of your life. Someone would say, "Let's catch that gopher," as he pointed toward an animal on the ground. First of all, you would know that it is pretty hard to catch a gopher by chasing it. Second, you would think that your friend was joking with you because he would be pointing at a land turtle. But land turtles are called gophers in Florida.

Now you can see how mixed up things would be if scientists had not worked out some scheme for finding out about all the different kinds of plants and animals in the world and giving each kind a name of its own. And when you remember that there are at least a million different kinds of plants and animals, you can imagine what a job it has been to study, name, and classify all the living things on this earth of ours.

Over 2000 years ago men began trying to work out some scheme for naming and classifying living things. Many plans were tried out, but none of them worked very well. Some kind of plant or animal that did not fit into the scheme was always bobbing up. It was different in some way from all the other living things. Men were unable at first to work out a scheme of classifying plants and animals because they did not know enough about them. They had not learned how to study living things as scientists study them today.

About 200 years ago in the land of Sweden two young students met at the University of Upsala, near Stockholm. These young men were Carl Linnaeus and Pehr Artedi. Carl had come to study medicine, and Pehr was studying to be a minister. They became very good friends. As they grew better acquainted, Carl learned that Pehr was greatly interested in chemistry and in fishes. Carl told Pehr that he liked to study birds and flowers.


FIG. 60. Carl Linnaeus

In their many talks about the wonders of nature these two young friends often discussed men's efforts to name and classify the living things and the materials of the earth. Perhaps their talk went something like this:

"Pehr, we really don't know anything about the world we live in. All the time, right here in Sweden, I see plants and animals and rocks that I can't name, and nobody else seems to know what they are. Yesterday, Pro-

fessor Rudbeck told me about a trip he once took way up north to Lapland. He saw plants and animals that he had never seen before. He couldn't find out what they were because he couldn't understand the language of the people."

"Yes," Pehr may have answered, "I know, because my home is near Lapland. There must be plants and animals all over the world that nobody knows anything about. Perhaps they are like the ones we have here in Sweden. Perhaps they are different. Names don't mean anything because no one person can understand all the languages. Furthermore, the names don't mean much because they do not tell us what these living things really are. The names that they have just tell us what they look like, or where they grow, or when they blossom, or something like that."

From many such talks as these the two young students at last got a great idea—an idea so great that neither they nor any other two men could have carried it out in a lifetime. They decided to name and classify every living thing in the world. Carl was to take the birds and the flowers, while Pehr was to take the fishes, the amphibians, and the insects.

These two friends studied and named thousands of plants and animals. Yet that was scarcely more than a beginning. However, it was a real beginning, and, what is more important, they worked out a plan for naming and classifying living things, and they invented a name-language. Both their plan and their name-language are understood and used by scientists and by educated people all over the world. Today a scientist in Russia, Sweden, China, India, or Japan can write to a scientist in any other country about a plant or an animal, and each scientist knows what the other is talking about.

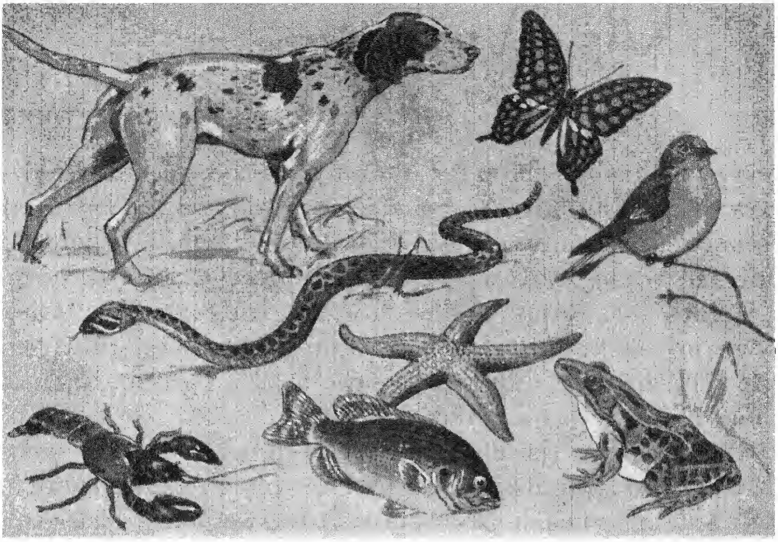


FIG. 61. A few examples of vertebrate and invertebrate animals

Problem 1:

WHAT DO SCIENTISTS DO WHEN THEY CLASSIFY LIVING THINGS?

BEFORE you begin to study the different groups of plants and animals, you should first see what scientists do when they classify living things. What was the scheme that Carl Linnaeus and Pehr Artedi worked out 200 years ago?

Study Figure 61 carefully. Look at each of the many different kinds of animals shown there. You can easily see that each animal has a different plan of structure; that is, each animal is built of different parts put together in different ways. Now the problem is to compare these animals. We want to find how they are alike and how they are different so that we can separate them into different groups. Each group must include animals whose structure is alike in certain ways. Furthermore, the animals of each group must differ in some way from the animals in the other groups.

Can you divide the animals in Figure 61 into two groups according to their structure? Probably not. The scientist,

however, has no difficulty in doing this because he knows how these animals are constructed. He would say that some of these animals have backbones, while others do not. He would put the starfish, the butterfly, and the crayfish into one group. They are alike in one way: They have no backbones. He would put the snake, the frog, the fish, the bird, and the dog into another group. Each of these animals has a backbone.

We have now done what we started out to do. We have divided the animals into groups, in this case, two groups. The animals in each group have at least one characteristic of structure that is alike. Furthermore, the plan of structure of the animals in one group is different from the plan of structure of the animals in the other group. One group of animals is called *vertebrates* because they have backbones. The other group is called *invertebrates* because they have no backbones. Are you a vertebrate or an invertebrate?

But *vertebrate* and *invertebrate* are pretty big words, and they stand for thousands of different kinds of animals. There are many kinds of vertebrates and many kinds of invertebrates. After all, the name *vertebrate* does not help us tell that a cat is different from a dog. We need some more group names to help us tell the different kinds of vertebrates and invertebrates. So the scientist divides the animals of these large groups into still smaller groups.

To show how this is done, let us see how the scientist divides the animals with backbones into smaller groups. Figure 62 shows some common vertebrate animals. Can you separate these animals into groups, so that each group includes animals that are alike in certain ways and yet are different in certain ways from animals of the other groups? You will probably have no difficulty in seeing

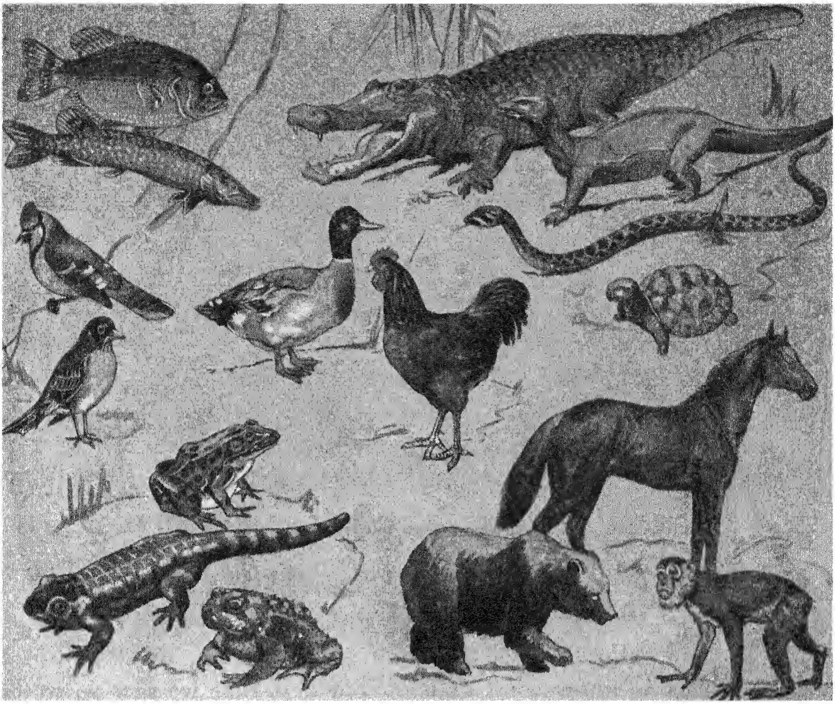


FIG. 62. All of these animals are vertebrates; that is, each one of them has a backbone.

that the fish all go into one group and the birds in another group. Fish have certain characteristics that other animals do not have, and so do birds.

The scientist puts the snake, the lizard, the alligator, and the turtle into another group, which he calls *reptiles*. These animals do not look much alike, but you will discover later that they have a like plan of structure—a plan that is different from the plan of structure of other groups. He puts the frog, the salamander, and the toad into another group that he calls *amphibians*. The horse, the monkey, and the bear go into a fifth group, called *mammals*. Later on in this unit you will learn just how each of these groups is different from the other groups.

Now let us select one of these groups and see what the

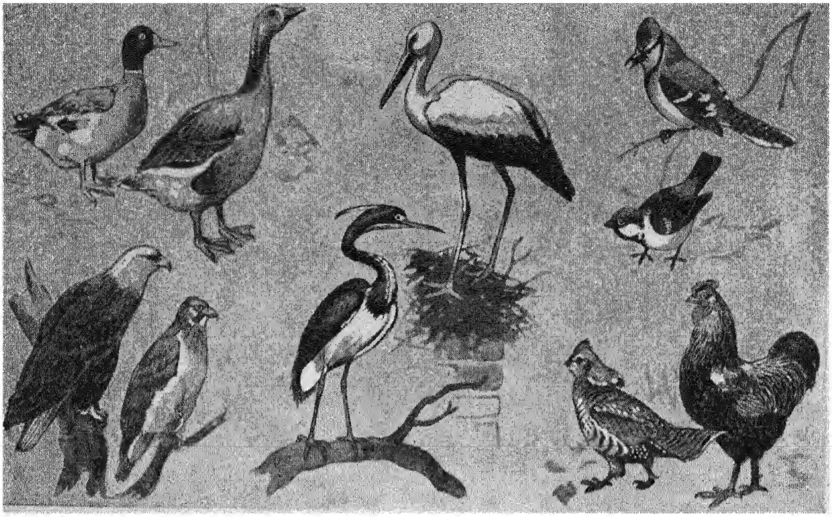


FIG. 63. A group of different kinds of birds

scientist does next. Look at Figure 63. At a glance you see that they are all birds. But the name *bird* is not enough. We use the name *bird* many, many times, but we also like to know what kind of bird it is that we see. So we next divide the birds into groups.

Can you divide these birds in Figure 63 into different groups? You see now that you must pay more attention to small details of structure because all of the birds are somewhat alike. You must look at the shape of the beak, the shape and position of the toes, the presence or absence of a web between the toes, the length of the legs, and many other parts of the bird. If you examine the pictures carefully, you may see why the scientists group these birds together: chicken and grouse, bluejay and sparrow, hawk and eagle, heron and stork, duck and goose.

Now look at Figure 64. These are all birds belonging to one of the groups mentioned above. To tell these birds apart, you must examine more details of their structure than you did before. You must consider the size of the bird, the color of the feathers on various parts of the body, and many other details.

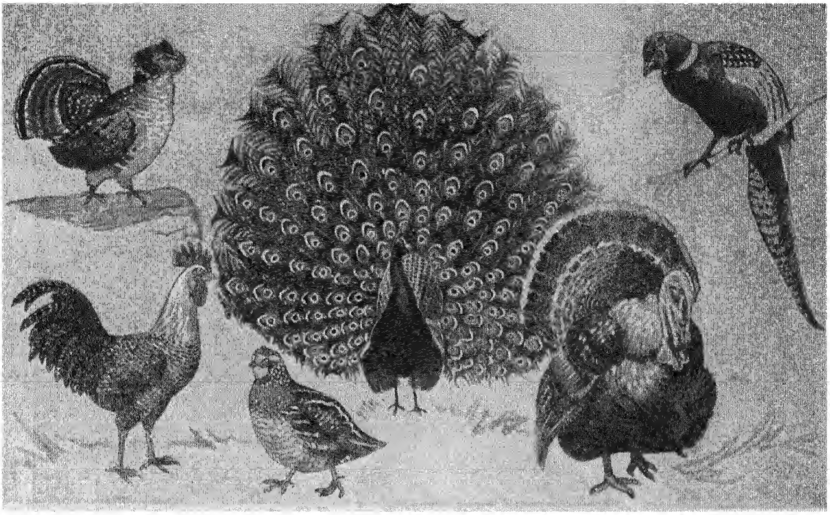


FIG. 64. All these birds belong in the same group as the chicken.

You will see, as you go from Figure 61 to Figure 64, that the animals are more and more alike. It would be possible to divide the last group of birds into still smaller groups. For example, you could select the chicken and show many different kinds of chickens, as you well know if you live on a farm. From such a picture you could name each different kind of chicken.

If you will look at Figure 65, you will see a diagram of what we have just described. You can see from this diagram how the scientist divides all animals into two groups, vertebrates and invertebrates. Then he divides the vertebrates into smaller groups. Each of these smaller groups is divided into still smaller groups. The scientist goes on dividing each group into still smaller and smaller groups until finally he is able to identify and name each particular animal.

The diagram, of course, does not show the complete scheme of classification for all animals of the world. A complete scheme would show also the different groups of invertebrates, as well as of the vertebrates. Then, each of these groups of invertebrates and vertebrates would be

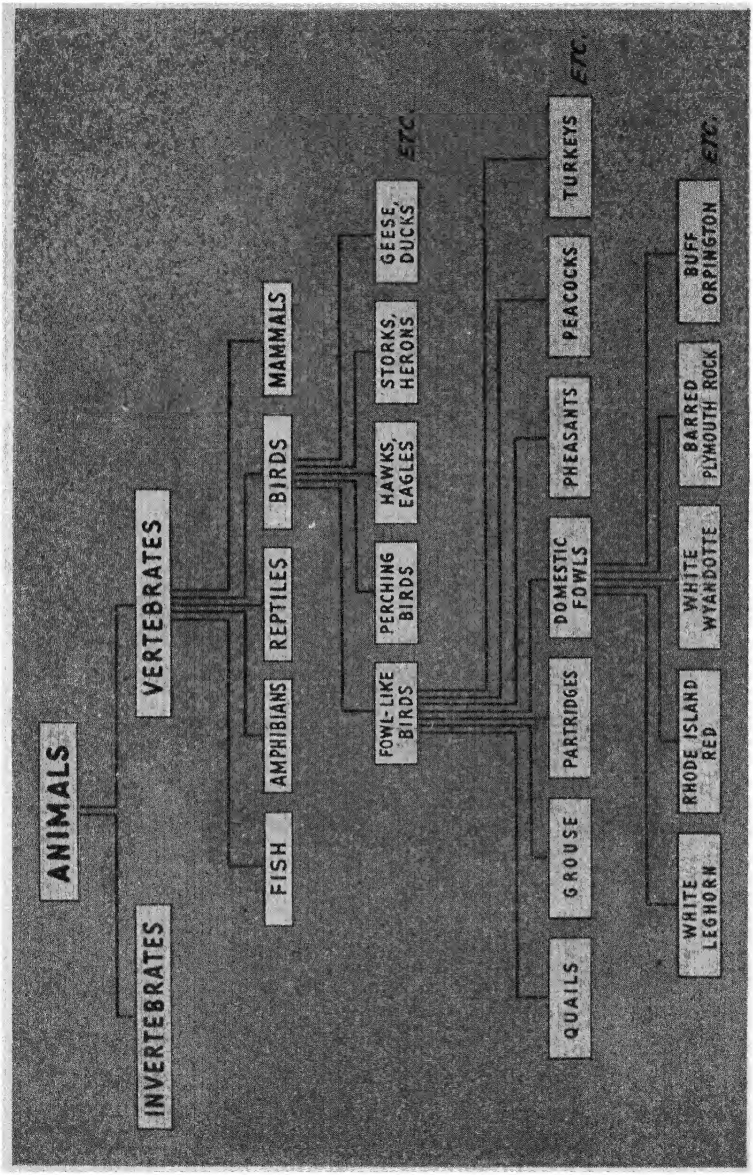


FIG. 65. This diagram shows how animals are divided into smaller and smaller groups according to their structure.

divided into smaller and smaller groups, as is shown in the diagram with the birds.

So far you have been reading about the classification of animals. Of course, plants, too, are classified. The same method of classification is used as with the animals. Different characteristics of structure are used as the basis of grouping and naming them. In the last problem of this unit you will learn how plants are classified.

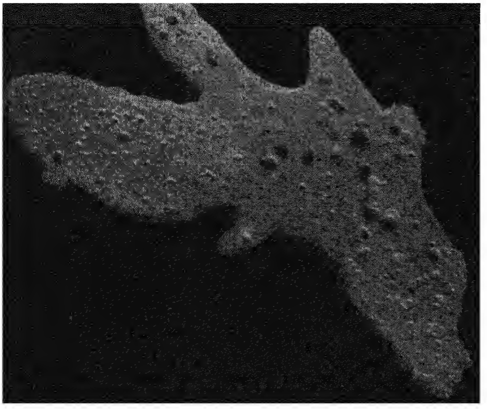
Now that you see the general scheme of classification, you will study some of the larger groups of animals and discover the characteristics of the animals that belong to these groups. In your science work this year, with all the other things you have to study, you of course cannot take time to learn about all the different groups of animals. So we have selected some of the groups of animals that you are most likely to see or hear about. In each group we have chosen one or more animals to study. Other animals of the same group are not exactly like the kind of animal that was described, but they do have the same general plan of structure.

When you learn the characteristics of the group as a whole, then you know that each animal in the group has these characteristics, too. You can see, therefore, that when you discover to what group an animal belongs, you know immediately many things about the general plan of structure of its body.

Self-Testing Exercises

1. Which one of the following characteristics is used by the scientist to classify animals into large groups? (*a*) Where the animal lives. (*b*) The appearance of the animal. (*c*) The structure of the animal. Why is this characteristic used?

2. Look at Figure 61. In what way are reptiles, amphibians, fish, birds, and mammals alike?



the high power of a microscope (P. S. Tice photo)

3. From what you already know, explain how birds are different from all the other groups of animals.

4. Explain fully what Figure 65 shows.

Problems to Solve

1. Work out a plan of classification for some group of individuals: the members of your class, the trees near your home, or the plants in your garden. State clearly what characteristics you use for your plan of classification.

2. How many examples of ways of classifying things can you name? Make a list, and after each example state what characteristic or characteristics are used to separate the different individuals into groups. For example, chinaware is the name of a group. How is chinaware classified?

3. How many advantages can you find in the classification of things?

Problem 2:
WHAT ARE THE KINDS OF ANIMALS THAT HAVE NO BACKBONES?

WHAT ARE THE SIMPLEST ANIMALS LIKE? Most of the animals you see—your pets, farm animals, and animals in zoos and circuses—have backbones. Therefore you may think that there are more kinds of animals with backbones than there are animals without backbones. But this is not true. Only about five per cent of all the kinds of animals in the world have backbones. The remaining ninety-five per cent are invertebrates.

It is hard to believe that an animal could be so small that it would take one hundred-fifty of them laid side by side to reach one inch. The ameba, however, is such an

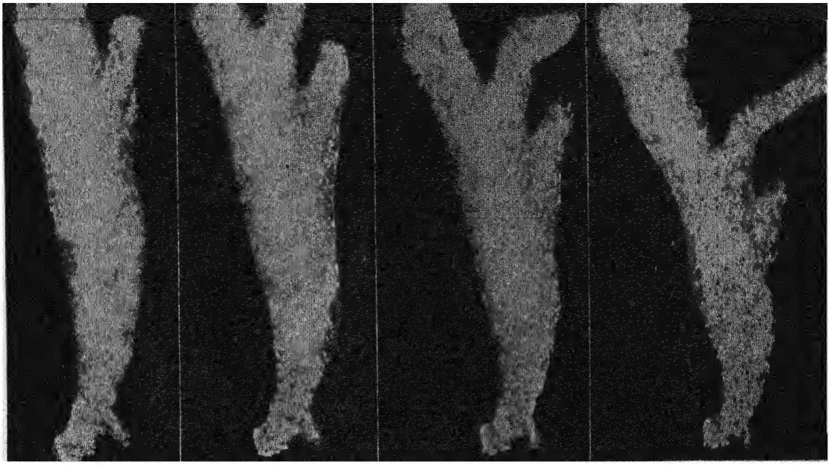


FIG. 67. In each of these pictures the ameba has a different shape because it has moved. (P. S. Tice photos)

animal. Over 22,000 of these tiny animals would be required to cover one square inch of surface. If you have not seen an ameba before, you should watch one. These little animals are famous because they are so simple.

EXPERIMENT 5. *What Is the Structure of the Ameba?* Collect some leaves or grass from a damp place. Place them in a large glass jar or dish and cover with water. The water should not be more than one and one-half inches deep. Cover with a glass plate and allow to stand for two or three weeks in indirect light.

Place the mouth of a medicine dropper close to the leaves or grass in the bottom of the jar, squeeze the rubber, and then release it so that a little water will enter the dropper and carry some of the sediment with it. Place a drop of the water on a slide and cover it with a cover-glass. Use the high power of a compound microscope to look for tiny clear spots, like those in Figure 67, that are slowly changing their shapes.

Under the microscope this animal looks like a blob of colorless jelly. If you watch it for a while, you will find that it moves (Figure 67). It has no legs, wings, or fins to move it about, but still it moves. Watch closely, and you will see a little bit of the jelly-like substance begin to

bulge out at one side. This bulge gets bigger and bigger, and finally the whole animal flows along in that direction. While the ameba cannot move very fast, still it can move.

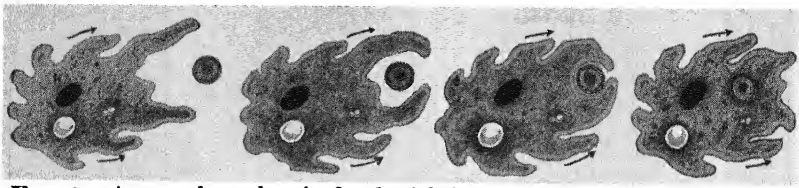


FIG. 68. An ameba takes in food with its entire body.

All of the animals that we ordinarily see have mouths that they use to take in food. The ameba has no mouth, but still it can eat. If you are lucky, you may see it surround a piece of food, as shown in Figure 68. The food digests inside the ameba and finally becomes part of it. The ameba gets oxygen from the water by diffusion; that is, the oxygen dissolved in the water just soaks into the ameba's body. It can grow and reproduce. In fact, it can carry on each of the absolutely necessary activities of life that you and I carry on. However, it can carry on these activities without having the many complicated body parts that we have.

FIG. 69. Paramecia, magnified 330 times (Bausch & Lomb)

Now let us examine another kind of one-celled animal, the paramecium.

EXPERIMENT 6. *What Is the Structure of a Paramecium?* This little animal can easily be obtained by placing much green "scum" from a pond into a jar of water and leaving it for a week or more. Obtain a

drop of water from near the surface of the water in the jar. Place the drop on a slide. Look in the drop for tiny moving particles. Cover with a cover-glass and examine the drop under the low power of a compound microscope. When you find a paramecium, you will probably have to move your slide around to keep the animal in sight because these animals can swim quite rapidly for their size.

Notice the shape of the animal. It is sometimes called the slipper animalcule. Can you see why? (*Animalcule* means "tiny animal.") If you look closely at the surface of the body, you may be able to see tiny hairs, or *cilia*. The animal constantly moves these cilia back and forth. They propel the animal like hundreds of tiny little oars. Watch it swim. What kinds of movements does it make?

If you can find one of the animals feeding, observe it carefully. Do you see an opening into the body? Watch it carefully. Perhaps you can see the cilia on the edge of this opening. As these cilia move, they sweep a current of water with food particles in it into the body of the animal.

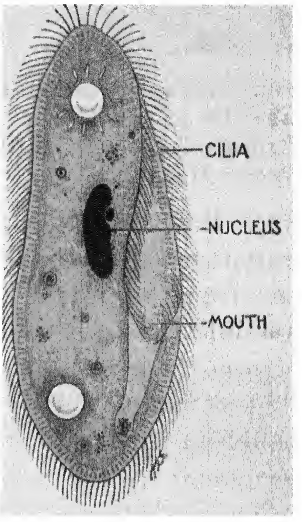


FIG. 70. The small gray bodies are *food vacuoles*, containing pieces of food being absorbed into the paramecium's body. The white bodies are *contractile vacuoles*, which get rid of excess water.

The paramecium is an example of a complex one-celled animal. It is more complex than the ameba because different parts of the cell do different kinds of work.

The ameba and the paramecium belong to the group of animals known as the *Protozoa*, or one-celled animals. (*Protozoa* means "first animals.") There are about 15,000 different kinds of protozoans. They are all alike in one

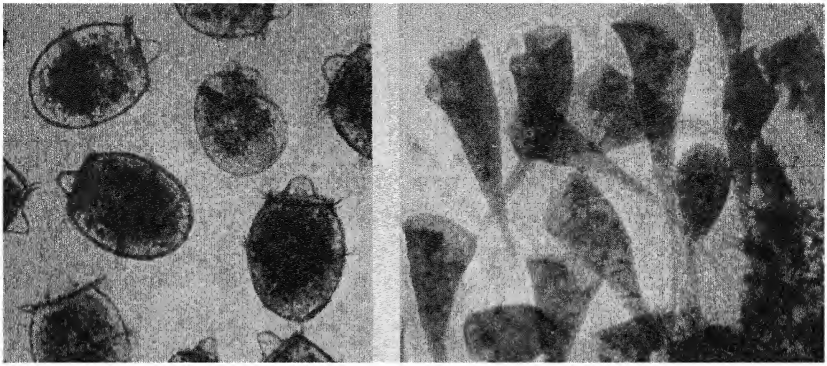


FIG. 71. The protozoans on the left are "nose" animals, called *Didinium* by scientists. They eat paramecia. The ones on the right are "trumpet" animals, or *stentors*. (Photo by G. Rommert, courtesy *Nature Magazine*)

way: Each animal consists of but a single cell. This is the important characteristic that makes the protozoans different from all other kinds of animals. It does not seem possible that one-celled animals could be constructed in fifteen thousand different ways, but it is true, nevertheless. Scientists have actually seen all these different kinds under the microscope. In Figures 71 and 72 you see some of the different forms of one-celled animals.

Everywhere you go, you will find protozoans. You will not see them, but they will be there. Stagnant water is swarming with millions of them. Even our drinking water is likely to contain a few harmless ones. They are found inside the bodies of most animals. They can live under almost any condition of life. They can dry up into tiny particles and blow about as part of the dust in the air. When water and food are again available, they become active again. Some of them cause serious diseases. One kind of ameba causes dysentery. Another kind of protozoan causes malarial fever. Many kinds are used as food by slightly larger animals.

There are so many millions of these protozoans that any guess that we might make of their number would be millions of times too small. A glass of water in which

any kind of plant or animal material is decaying may have thousands of these tiny animals in it.

Self-Testing Exercises

1. In what way are the ameba and the paramecium alike?
2. How are protozoans different from all other groups of animals?
3. Why is the paramecium said to be a more complex animal than the ameba?
4. Copy the statements below. Check each statement as true or false; that is, mark it T or F.

a) A protozoan can move.
b) A protozoan can take food into its body.
c) A protozoan can digest food.
d) A protozoan takes oxygen into its body.
e) A protozoan can grow.
f) A protozoan can reproduce.
g) A protozoan can think.

5. If a bunch of dry leaves or grass is kept in water for a week or two, protozoans can usually be found in the water. How did they get there?
6. In what way do protozoans affect our lives?

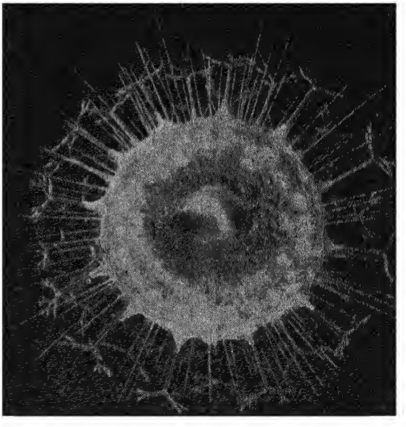


FIG. 72. This protozoan receives the name *radiolarian* from the fine threads of protoplasm that radiate in all directions. (American Museum photo)

Problems to Solve

1. What are some of the common kinds of protozoans in addition to amebas and paramecia? Look in zoölogy books to find pictures and descriptions of kinds not shown in this book.
2. How many different kinds of protozoans can you find for yourself? If you have the use of a microscope, collect material from ponds and other

FIG. 73. The sponge dock at Tarpon Springs, Florida. Sponges are found in almost all the waters of the world and at all depths, but they grow best in warm waters.

bodies of water and examine it for protozoans. Always put a tiny amount of water plants or debris from the bottom on your slide. The animals are more apt to be found in this material. They will become more abundant if grown as directed for paramecium on page 88. Such a culture will usually contain several kinds of animals. If allowed to stand for several weeks, the kinds gradually change in numbers. Keep a record of your discoveries by means of notes and drawings of the animals you find.

WHAT KIND OF ANIMAL IS A SPONGE? Do you know that the sponge you use in washing the car was once a colony of living sponge animals? At one time this colony of sponges was living on the bottom of the ocean. If it was living in shallow water, it was dragged from the bottom by a long-handled rake. If it was living in deep water, it was gathered by a diver. Then it was thrown out on the shore. Here the living part of the sponge died and decomposed. The skeleton of soft, fibrous material did not decompose. It is this skeleton that we use to wash windows and automobiles and for other purposes.

You can find out more about the structure of a sponge if you examine a simple sponge animal, such as is shown in Figure 74. Notice that the animal is shaped like a vase. There are usually one or more large openings in the animal. When colored particles are added to the water near one of these openings, you can see that a current of water is being forced from this opening. If water is coming from the body of the sponge, there must, of course, be some way for water to get in.

Actually, there are thousands of tiny openings, or pores, in the surface of the animal. It is through these pores that water, food, and oxygen pass into the animal and circulate through it. The walls of the smaller passageways are covered with tiny whip-like hairs. These hairs move back and forth and cause a current of water to flow into the pores and out through the large openings. This water brings in food and oxygen for the sponge cells.

The plan of structure of the sponge is very simple. It is a solid body with irregular channels running through it. The sponge has no organs, such as a heart, lungs, or a digestive tube. Food is taken from the water by the cells, and digestion takes place in the cells. The adult sponge is always attached to some surface and does not move around.

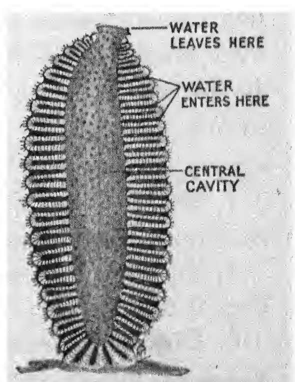


FIG. 74. Diagram of a simple sponge

In an animal as large as a sponge you might expect to find some kind of nervous system. A nervous system, as you know, needs cells to receive stimuli and send them on through nerve fibers to the rest of the body. Without a system of this kind the whole animal cannot respond to stim-

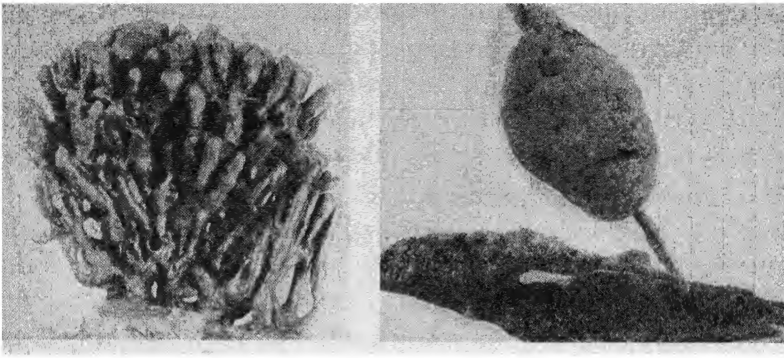


FIG. 75. At the left is a red-beard sponge; at the right, a fresh-water sponge. (American Museum photo)

uli. The sponge, however, has no nervous system. It has no special sense cells to receive stimuli and no nerve cells to send stimuli around the body. Thus each individual cell responds to the stimuli that reach it.

The most important characteristic that distinguishes the sponge animals from all other animals is the possession of millions of tiny pores. It is this characteristic that gives the group its name, *Porifera* ("pore-bearers"). Sponges have been found as far down in the ocean as men have ever gone, and they have been found almost everywhere in the world. Scientists have so far discovered and named about 2500 kinds.

Self-Testing Exercises

1. What is the most important characteristic that makes sponges different from all other animals?

2. (*a*) How does water flow through a sponge? (*b*) What path does it follow?

3. How does the sponge get its food?

Problem to Solve

How is sponge "fishing" carried on? Consult reference books and prepare a talk on sponges.

FIG. 76. This hydra has captured a water flea for food. (G. T. Hillman photo)

WHAT IS THE STRUCTURE OF THE COELENTERATES? Figure 76 shows an innocent looking animal, the hydra. The hydra is only about one-half inch long, yet it can capture and eat an animal many times as large as itself. It is really very dangerous to certain other animals. Let us watch it in action. Here comes a small water flea. As the flea swims by, it brushes the *tentacles* of the hydra. Then it suddenly stops. It struggles for a time and finally becomes quiet. The tentacles of the hydra are wrapped around it, and it is drawn down to the mouth of the hydra. Slowly it passes through the mouth into the hydra's body. It is dinner time for the hydra.

To understand how the hydra could capture the water flea, you will need to know something about the structure of the hydra. On the hydra's tentacles are great numbers of cells that shoot out threads when they are touched (Figure 77). Some of the threads are hollow and contain a poisonous substance. When a number of these threads penetrate an animal, they paralyze or kill it. Other kinds of threads that are shot out from the cells are wrapped around any hairs that may be on the prey and help to keep it from escaping. Now you see what

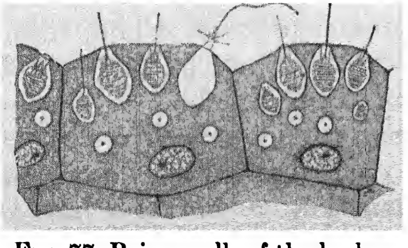


FIG. 77. Poison cells of the hydra

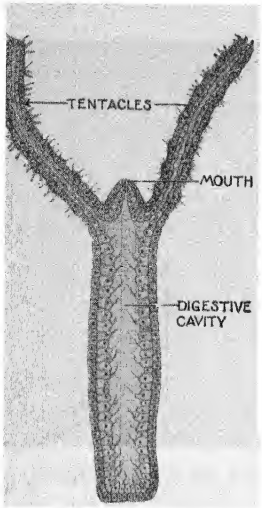


FIG. 78. A sectional view of the hydra

happened to the water flea. It was paralyzed by the poisonous threads shot out from the tentacles.

Now let us look at the plan of structure of the hydra. The body is vase-shaped with a cavity inside (Figure 78). The opening in the body is a real mouth through which food passes into the hydra. Some of the cells of the inner lining of the hydra are gland cells; these make digestive juices that can dissolve the food in the cavity. The dissolved food then diffuses into the cells that line the cavity and on into the outer cells of the hydra. Parts of the food that will not digest are passed out through the mouth.

Small as the hydra is, it has a nervous system made up of a network of fibers that extend through its whole body. This network is somewhat like the hair net that girls use to keep their hair from blowing. But in the nervous system of the hydra there is no central or controlling part, such as the brain. Sensory cells located on the surface of the animal pick up stimuli from objects they touch or from chemical substances in the water, and nerve cells carry the impulses to muscle cells. A stimulus thus may result in the contraction of the whole body, or of the tentacles, or of other parts

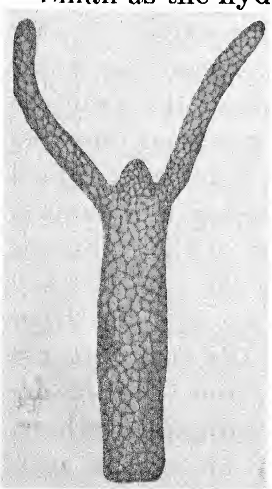


FIG. 79. The nervous system of the hydra

of the body. A nervous system is a great help to an animal. It helps different parts of the body to work to-

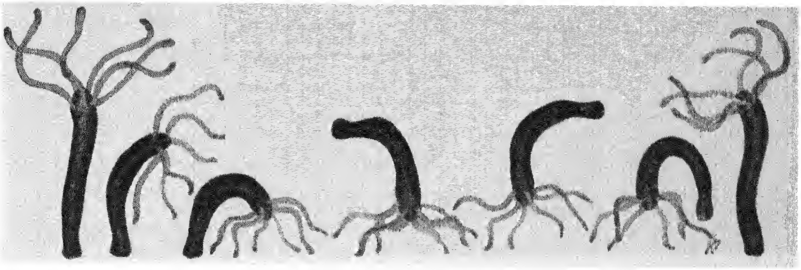


FIG. 80. Sometimes the hydra travels by turning slow somersaults.

gether. For example, when food touches one tentacle, the stimulus is sent on to the other tentacles, and all of the tentacles then work together to cram the food into the mouth.

Unlike the sponge, the hydra can move about. It may slide along on the lower end of its body, or it may bend over, attach its tentacles to a new point, and then bring up the lower end of its body, much as a measuring worm does when it moves along. Small as it is, the hydra gets along wonderfully well in its environment.

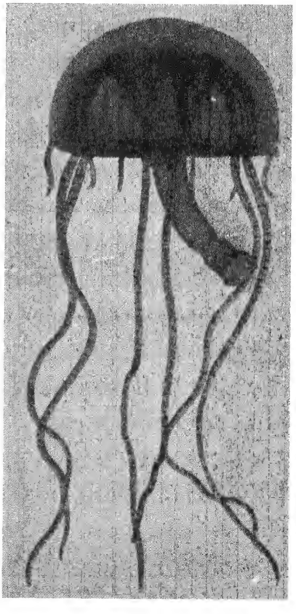


FIG. 81. A jellyfish (Roy Pinney photo)

It may be difficult for you to see why the hydra, the jellyfish, and the sea-anemone (Figure 82) are classed together in the same group, called *Coelenterata*. An outside view of them, such as is shown in the pictures, would lead

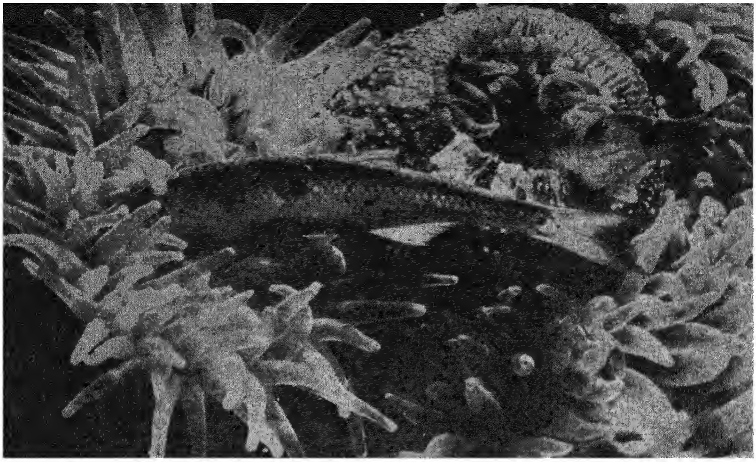


FIG. 82. These flower-like animals, the sea-anemones, have caught small fish with their many tentacles. (Three Lions photo)

one to believe that they have few, if any, characteristics that are alike. Scientists, however, are not deceived by external appearance; they are interested in the way in which the animals are put together.

Careful examination of these three animals shows that each has a central cavity in its body that is used as a digestive cavity (Figure 83). Into this cavity there is only one opening, the mouth. Every coelenterate has tentacles with stinging cells that are found in no other animal outside this group. Every coelenterate is built on a circular plan. These and other facts of structure tell scientists that an animal is a coelenterate.

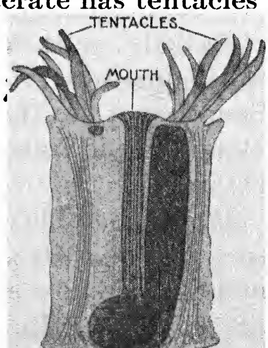


FIG. 83. A sectional view of a sea-anemone

Coelenterates are found both in fresh and in salt water. The fresh-water hydra can be found in ponds and streams clinging to water plants, dead leaves, and sticks. If some of these are brought into the classroom and placed in jars of water, hydra

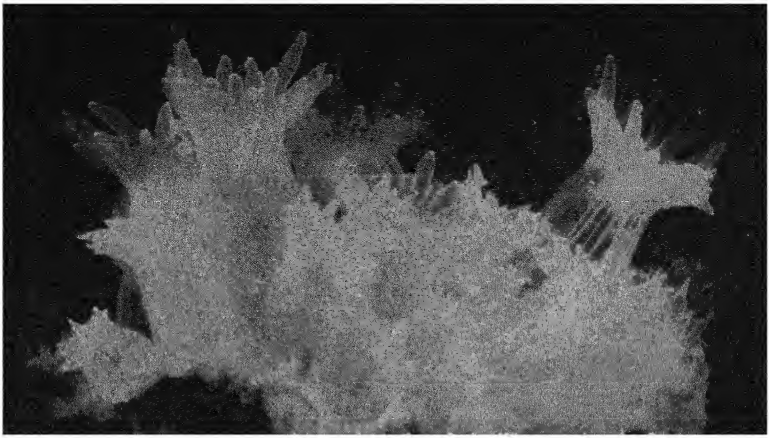


FIG. 84. What is the resemblance of the star coral to other coelenterates? (American Museum photo)

may be found clinging to the walls of the jars. It is in warm shallow seas, however, that coelenterates are found in the greatest abundance. In many places the ocean floor is almost covered with them (Figure 55).

Among the many interesting coelenterates are the different kinds of coral *polyps*. From the lower surface of their bodies these animals give off lime. This lime forms a limestone cup. Many coral polyps live together and build up solid masses of limestone or branching tree-like structures. New polyps build on the limestone made by the first polyps, and gradually a reef is formed that extends up to the surface of the water. Many tropical islands are coral islands, that is, islands built by coral polyps.

Self-Testing Exercises

1. What is the plan of structure of coelenterates? Tell several things about the plan.
2. How do the coelenterates differ from the sponges?
3. Why are coelenterates able to use fairly large animals for food?
4. Why can the coelenterates respond to stimuli better than the sponges can?

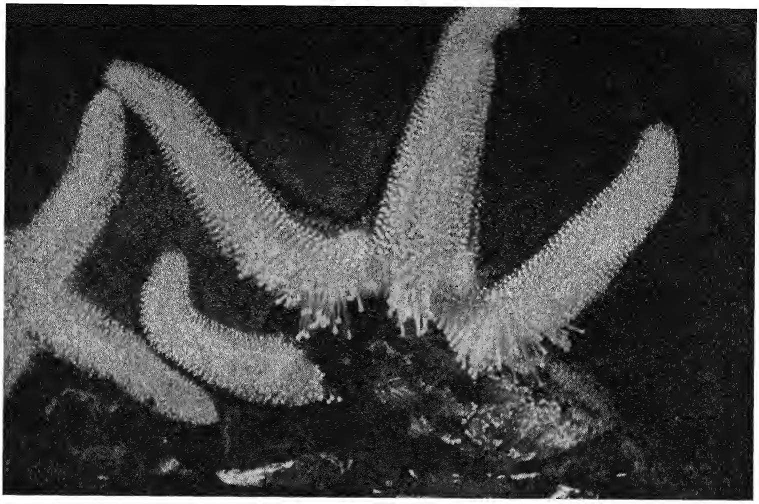


FIG. 85. How a starfish opens a clam shell (Photo by W. K. Fisher, Pacific Grove, Calif.)

Problems to Solve

1. All coelenterates live in water. Can you see any reasons why they could not live on land?
2. What other kinds of coelenterates are there in addition to hydras and coral polyps? Read about them in encyclopedias, zoölogy books, and other reference books.

WHAT IS THE STRUCTURE OF THE ECHINODERMS? Strange as it may seem, there is one animal that can digest its food outside its body. This animal, the starfish, is very fond of oysters. Oysters, as you know, are enclosed in two hard shells. Strong muscles pull these shells together when the oyster is disturbed. But the starfish has its own method of opening an oyster's shell and eating the soft-bodied animal that is inside.

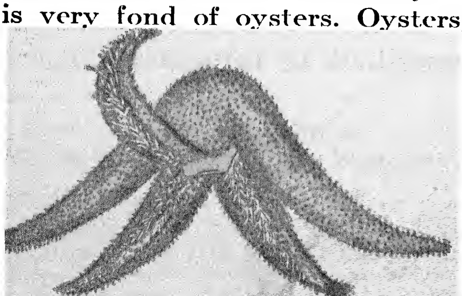


FIG. 86. A starfish forcing its stomach out through its mouth

First, the starfish arches itself over the shell in a humped-up position, so that all its arms are touching the shell. On the bottom of the arms are hundreds of little *tube feet*, each with a tiny sucker on the end. These suckers hold on like little vacuum cups. The starfish attaches many tube feet to the shell and pulls. The starfish also gives out some stomach juice that enters the oyster and paralyzes its muscles. The muscles can no longer hold the shell closed and it opens exposing the oyster's soft body.

Then a curious thing happens. The starfish forces its stomach out through its mouth (Figure 86), and the stomach is wrapped around the soft body of the oyster inside the opened shell. Digestive juices begin to flow, and gradually the body of the oyster is digested and absorbed by the lining of the starfish's stomach. Then the starfish pulls its stomach back into its body. Because it eats oysters, the starfish is a great enemy of the oyster fisherman. Whenever starfish are caught, they are killed.

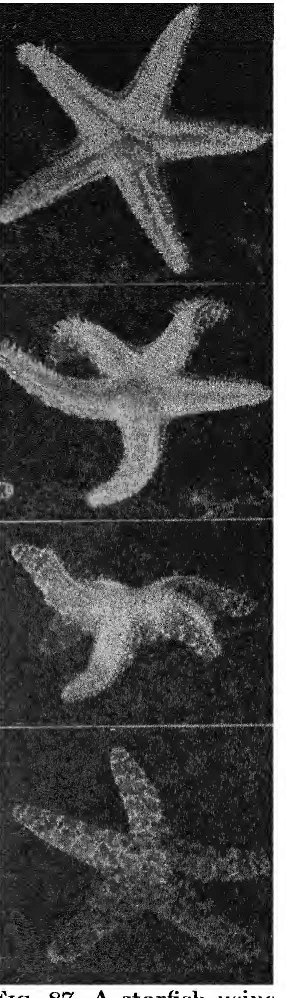


FIG. 87. A starfish using its arms to turn itself over (Photos by Dr. Ralph Buchsbaum from his *Animals Without Backbones*)

The starfish belongs to the group, *Echinodermata*, which means "spiny skinned." If you will rub your hand over a live or a dried starfish, you will see how appropriate this

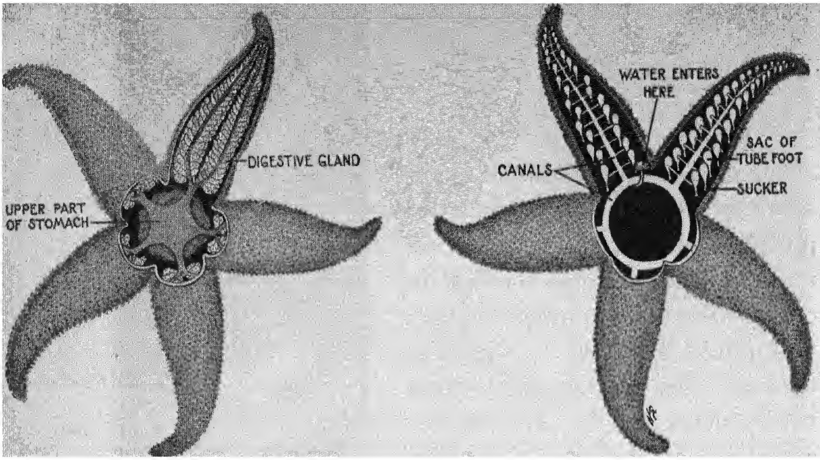


FIG. 88. The digestive system of the starfish

FIG. 89. The water-vascular, or water-circulatory, system of the starfish

name is. Most of the starfish that we see are dried. You might get the idea that the whole body is stiff, but this is not the case. The arms of the starfish are very limber and can be moved into many different positions (Figure 87).

Figure 88 shows how a starfish is constructed. Let us first look at its digestive system. The mouth opens into a loose, baggy stomach. Five pairs of digestive glands, one pair for each arm, branch off from the stomach. Small, partially digested particles of food pass into these glands, where they are digested and absorbed. Undigested particles pass out through the *anus* or back through the mouth.

If you compare the digestive system of the starfish with that of a coelenterate, you can see one way in which the starfish is different. In the hydra, for example, there is a central cavity in the body of the animal that is also the digestive cavity. In the starfish there is a special digestive system (stomach and glands) inside the body cavity.

The most peculiar structure in the starfish is the *water-vascular*, or circulatory, system (Figure 89). Water enters a tube in the body of the starfish through some tiny openings in the upper surface of the starfish near the center of

its body. It passes through a series of canals into each of the arms. Hundreds of tiny tube feet are connected with these canals. These tube feet end in suckers. Each tube foot is connected to a small, muscular sac inside the starfish. When the sac contracts, it forces water into its tube foot and thus pushes the tube foot out. The sucker attaches itself to the surface on which the animal is moving. Then muscles in the walls of the foot contract, and the tube foot gets shorter, forcing the water back into the muscular sac. In this way the starfish pulls itself over the rocky bottom. You can see now how these tube feet hold on to the shell of the oyster and how hundreds of them working in relays can finally force the shell to open. In sand or mud starfish move by using their tube feet and arms as legs.

The starfish gets oxygen by means of many tiny gills. These gills are small thin-walled tubes that extend from the body of the animal into the surrounding water. They are protected by the spines on the body of the animal. Oxygen dissolved in the water soaks, or diffuses, into the gills, and this oxygen is passed on into the watery fluid that fills the body cavity of the animal. In the same way carbon dioxide diffuses out through the gills into the sea water. The starfish also has a nervous system. There is a nerve ring around the mouth and a branch from this ring to each of the arms. Several smaller nerves are connected with the upper and lower sides of the animal.

This nervous system enables the animal to control what it does. For example, there are hundreds of tube feet used in movement. These tube feet have to work together to move the animal in a certain direction. If you could watch a starfish move, you would see how this is necessary. Any one if its five arms may serve as a temporary head. One

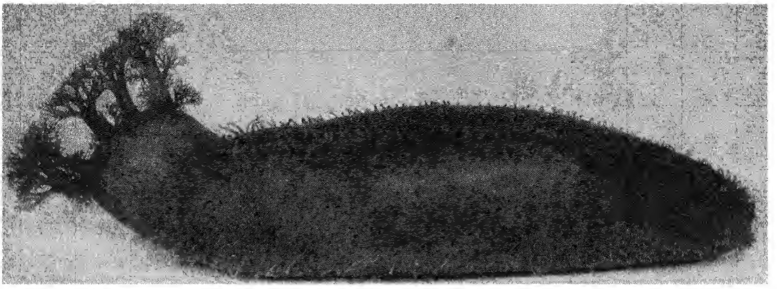


FIG. 90. Why do you think the sea-cucumber belongs to the echinoderm group? (Roy Pinney photo)

of them is curved upward so that a little red eye on the tip can "see" (very dimly) any danger ahead. If this arm is tapped, or if for some reason the animal decides not to continue in a given direction, this arm drops and another arm is raised. Then the animal travels in the new direction. When this happens, of course the tube feet must change their direction of pull. This change of movement is made possible by the nervous system that controls the whole animal.

You can see that the starfish is a much more complex animal than any animal we have studied before. It has several different systems, each of which carries on a certain work for the animal. The most common animals of this group are the starfish, sea-cucumbers, brittle-stars, and sea-lilies. About 4500 different kinds of echinoderms are known. All of these animals have a spiny or leathery skin. All have bodies that are built on a circular plan. All have a water-vascular system. No other group of animals has such a system.

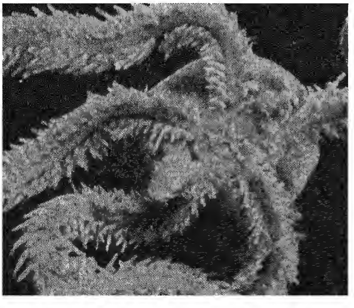


FIG. 91. This picture shows the underside of a serpent star, another echinoderm, with its hundreds of tube feet. (Tice photo)

FIG. 92. This picture shows the segments in the body of the earthworm. (Cornelia Clarke photo)

Self-Testing Exercises

1. In what important ways are the echinoderms different from the coelenterates?
2. Why are the echinoderms considered to be more complex than the coelenterates?
3. What characteristics are used to distinguish the echinoderms from other groups of animals?

WHAT ARE THE CHARACTERISTICS OF THE SEGMENTED WORMS? You never pay much attention to earthworms except when you are going fishing. Earthworms are, however, very valuable to man, as you may remember from your previous study. They burrow through the earth and make holes that enable water and air to enter the soil. They also move the soil from the holes to the top of the ground. Thus they gradually mix the lower soil with the upper soil.

If you will study the structure of an earthworm closely, you will see that its body is divided into sections, or *segments*. Its body is streamlined, and therefore the animal can work its way easily through the small holes in the soil. Its body also has small, movable bristles on it. If you will rub your fingers along the sides, you can feel these small bristles. They are used by the earthworm as tiny spikes to help it move.

In moving forward, the earthworm extends the front bristles and gets a grip on the soil. The rear bristles are

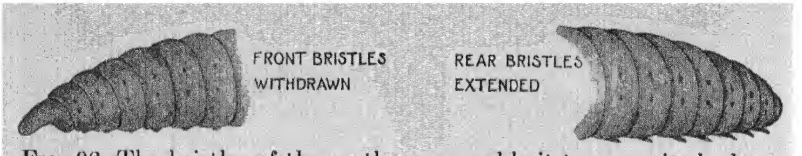


Fig. 93. The bristles of the earthworm enable it to move its body.

withdrawn. Then the muscles running lengthwise pull the rear part forward. Next, the rear bristles are extended, the front bristles are withdrawn, and muscles in the body force the front part of the body forward.

The earthworm has no definite eyes, but there are cells, mostly in the front end of its body, that are sensitive to light. It has a very poor sense of smell, and it cannot hear. It is, however, sensitive to vibrations. It is said that earthworms can be captured by pounding a stick into the ground and then moving it backward and forward. The worms, disturbed by the vibrations, will come to the surface. The earthworm has a nervous system that includes a brain as well as sensory cells and nerve fibers. Of course the brain is not a brain like your brain. It does, however, help control the activities of the worm. All of the animals that we will discuss from this point on have a central nervous system that controls their activities.

As the earthworm burrows through the soil, the soil passes through its mouth into the digestive tube. Digestible parts of the soil (plant and animal materials) are

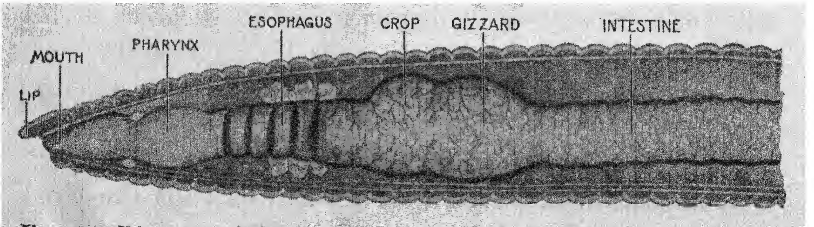


Fig. 94. Diagram of the digestive system of the earthworm

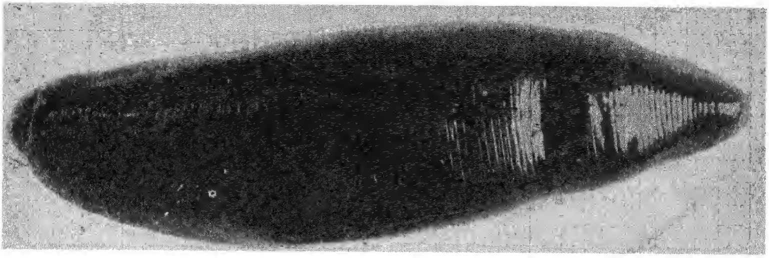


FIG. 95. A leech is also a segmented worm. (Cornelia Clarke photo)

used by the worm, and undigestible parts pass out through the anus. The worm thus eats its way through the soil. When food passes into the body of the earthworm, it goes into the crop, which is just an enlargement of the food tube (Figure 94). From here it passes into the *gizzard.* The gizzard has heavy muscular walls that contract and expand. The food is thus churned and ground into small pieces by tiny stones that are swallowed with the soil. The ground-up food then passes into the intestines, where it is digested and absorbed.

Earthworms have a series of blood vessels that pass through the body. The blood is pumped through the body by five pairs of hearts. These hearts are really nothing but enlargements of the blood tubes. Oxygen diffuses into the body through the skin. The skin must be kept moist for this purpose. When earthworms are exposed to dry air or to the heat of the sun for a short time, they die because their skins dry up; they can no longer get oxygen through the dried-up skin.

The best time to catch earthworms is on a warm, rainy night in spring or early summer. If you will take a flashlight with you, you will have no trouble in locating them. You will find them crawling on the ground in search of food. Because of this habit of coming out at night, the

large kinds are often called "night crawlers." After a heavy rain you often see many earthworms. The rain fills their burrows, and they are driven out of the soil by lack of oxygen. In the winter they burrow deep in the soil, and usually several of them roll up together in a ball.

Sand worms, tube worms, and leeches are other members of the group to which the earthworm belongs. This group is called *Annelida* ("ringed"). The main characteristic of this group is the division of the body into segments of nearly the same shape. All have a complete system of blood tubes and a tube-like digestive system with two openings, the mouth and the anus. About 4000 different kinds of worms belong to this group.

Self-Testing Exercises

1. What is the main characteristic of the annelids?
2. How does an earthworm get food? How is the earthworm able to make holes through the soil?

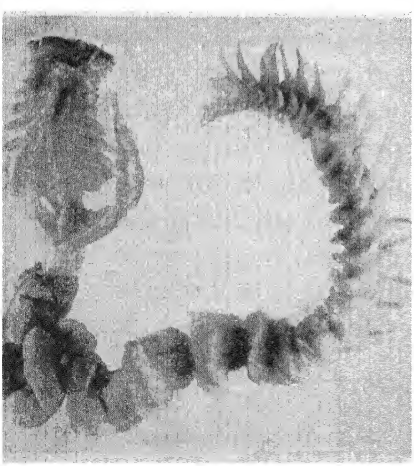


FIG. 96. This weird-looking worm is an annelid. (P. S. Tice photo)

Problems to Solve

1. Show how the habits of the earthworm are related to the structure of its body.
2. What can you learn about earthworms for yourself? Get some large earthworms and put them in a pan lined with moist towel paper. Watch the worms carefully to learn all you can. See what effect light and darkness have on the worms. Try the effect of touch on them. Can you see blood moving along in tiny vessels just under the skin of these animals? Write a story of your observations.

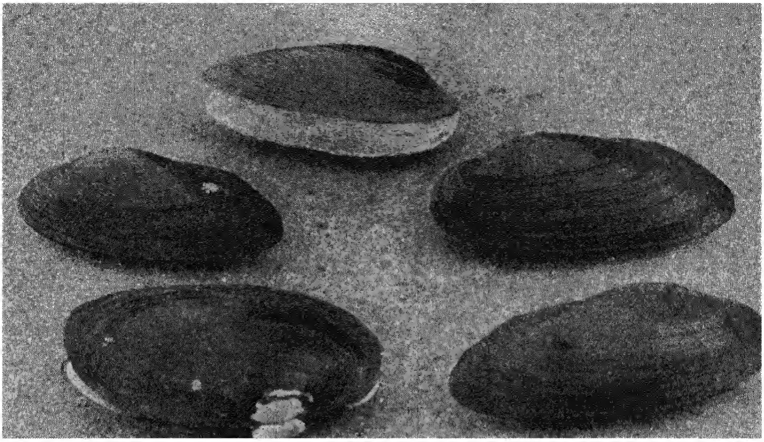


FIG. 97. Fresh-water mussels, or clams (Cornelia Clarke photo)

WHAT ARE THE CHARACTERISTICS OF THE MOLLUSKS? Have you ever eaten a *mollusk?* The name mollusk comes from the word *mollis*, meaning *soft*. One characteristic of the mollusk is its soft body. The animals that belong to this group appear to be quite different from each other. The group includes slugs, snails, oysters, clams, mussels, squids, octopuses, and other animals. Which of these have you eaten? Some of these animals, such as oysters, clams, and snails, are protected by an armor in the form of a hard shell.

Figure 98 shows the structure of a fresh-water mussel, or clam. At the rear end of the clam is a short, double tube that opens into the water. Cilia inside the clam force a stream of water to flow in one tube and out the other. Small plants and animals carried by the water are swept into the mouth of the clam to serve as food. The stream of water, without food, then passes through lattice-like gills and out through the other tube.

Quite different in appearance is the land snail. It may remain completely within its shell and thus be protected from its enemies, or it may force its body entirely out of its shell. One way in which it is different from the clam is

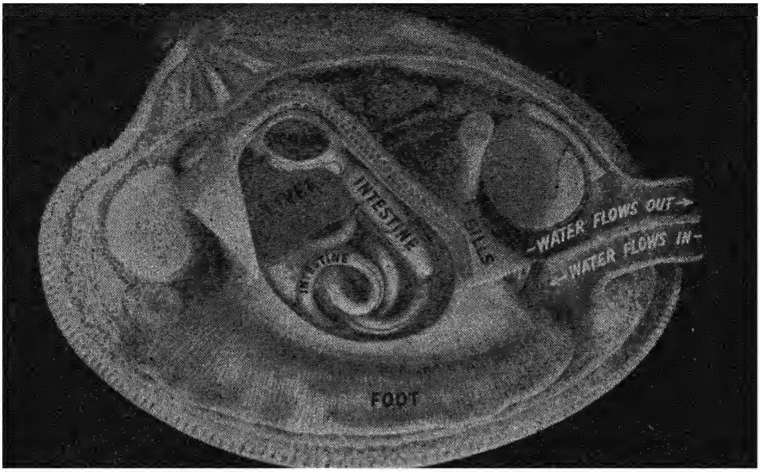


FIG. 98. A fresh-water mussel usually lies half buried in the mud, but it can move by working the muscles of its foot through the mud. (American Museum photo)

that it has a head. On this head are four tentacles, one pair of which is used as feelers; the other pair has eyes on the ends. These tentacles can be moved around so that the snail may bring its eyes closer to the objects that it examines.

If you ever watched a land snail move, you are probably curious as to how it does it. The lower surface of the foot pours out mucus, a slimy, slippery substance. Muscular contractions, something like waves on water, pass from one end of the foot to the other. These muscular waves move the snail along the slippery path that it has made.

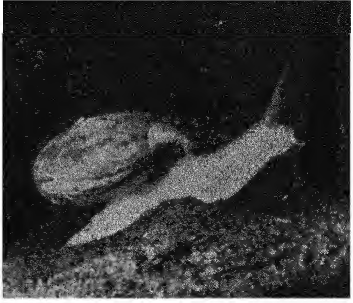


FIG. 99. A land snail "on the move" (Hugh Spencer photo)

Perhaps the most interesting mollusks are the octopuses, or devil-fishes. The devil-fish has eight arms provided with suckers to help the animal hold its

FIG. 100. This is a photograph of a baby octopus only a few days old. (P. S. Tice photo)

prey. Stories have been told that an octopus will attack a ship and destroy it. Specimens of the giant octopus with a diameter of twenty-eight feet have been found in the Pacific Ocean. It is unlikely that even so large a creature as this could attack a ship. Yet the large ones are very dangerous to meet in the water.

Unless you know a great deal about the structure of animals, it is often quite hard to see why the scientist classifies certain animals as he does. For example, it does not seem reasonable to class together in one group animals so different as the oyster and the octopus. These animals, however, do have certain characteristics that are alike, and they also have characteristics that are not found in any other animals. Therefore, they are classed together.

First of all, mollusks have soft bodies that are usually provided with a hard shell. Second, their bodies are not divided up into definite parts, or segments. Third, the parts that extend from the body, the *appendages*, such as the tentacles of the snail, are not jointed. No other group of animals has all these characteristics.

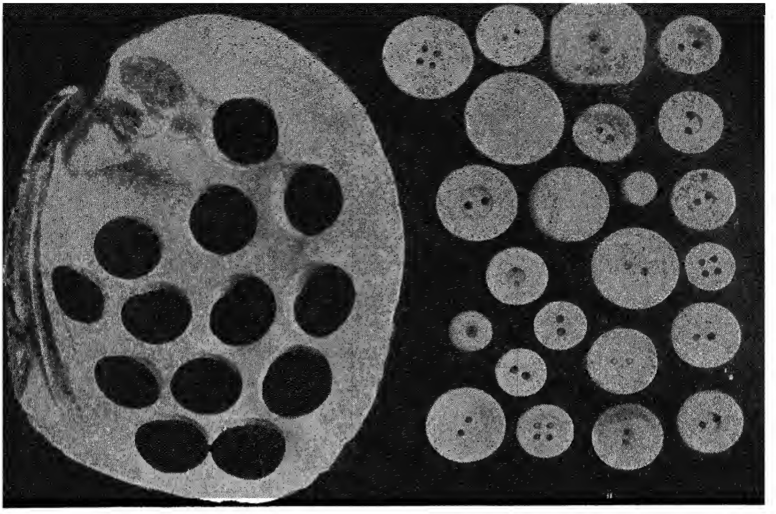


FIG. 101. Many of our so-called pearl buttons are cut from fresh-water mussels taken from the Mississippi. (Cornelia Clarke photo)

Self-Testing Exercises

1. In what ways are all mollusks alike?
2. Name four common kinds of mollusks.

Problems to Solve

1. Of what importance are mollusks to man? List as many uses as you can; then look for others in reference books. Look under the word mollusk and under the names of the different kinds of mollusks.
2. How do some mollusks produce pearls?
3. Stock an aquarium (any glass tank or dish or jar) with water plants. Add some snails from a pond or stream. Watch the snails to learn how they live.
4. If you have a good-sized glass tank containing sand and some water plants, try to get one or two small mussels for it. Watch them to learn as much as you can about how they live.

WHAT ARE THE CHARACTERISTICS OF THE ARTHROPODS? And now we come to the group of animals that includes more different kinds than all the other groups put together. This group is known as the *Arthropoda*, which means "jointed-legged." Over 500,000 kinds of animals belonging to this group have been discovered and named.

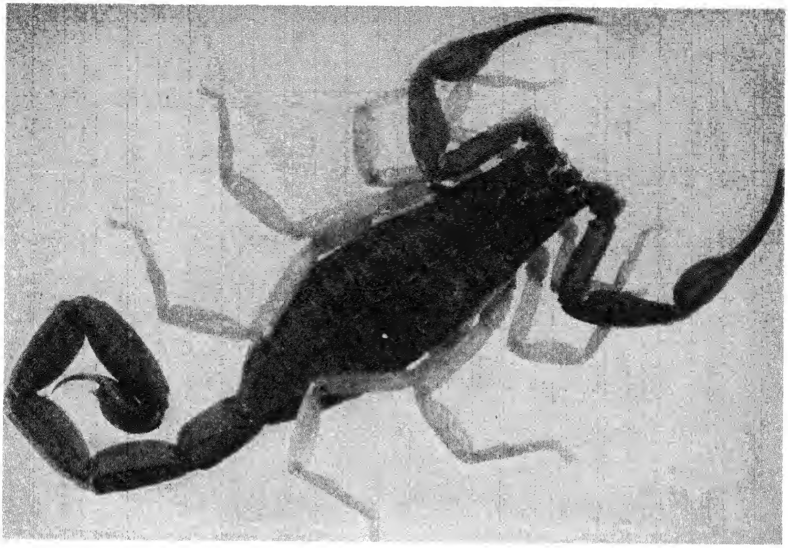


FIG. 102. A scorpion is an arthropod because it is an invertebrate with jointed legs. (P. S. Tice photo)

You already know many of these animals. Crabs, crayfish, lobsters, centipedes, spiders, daddy-long-legs, and insects, such as flies, beetles, bugs, grasshoppers, butterflies, moths, and crickets, all belong to the arthropod group. In the next problem you will study more about this enormous group of living things.

First, let us consider the characteristics of arthropods. What are their bodies like? Examine the legs of the animals shown in Figures 102, 103, and 104. You will observe that all of them are jointed. Furthermore, you will observe that other appendages, such as those found on the head and on the abdomen of the crayfish, are also jointed. None of the animals in the groups that you have studied to this point have jointed appendages. Turn back in your book and examine the animals shown in Figures 72, 75, 76, 80, 81, 82, 84, 87, 90, 91, 92, 98, and 100. You will find no jointed appendages in these animals.

Members of this group also have an external skeleton; that is, their skin contains a hard, horny material, called

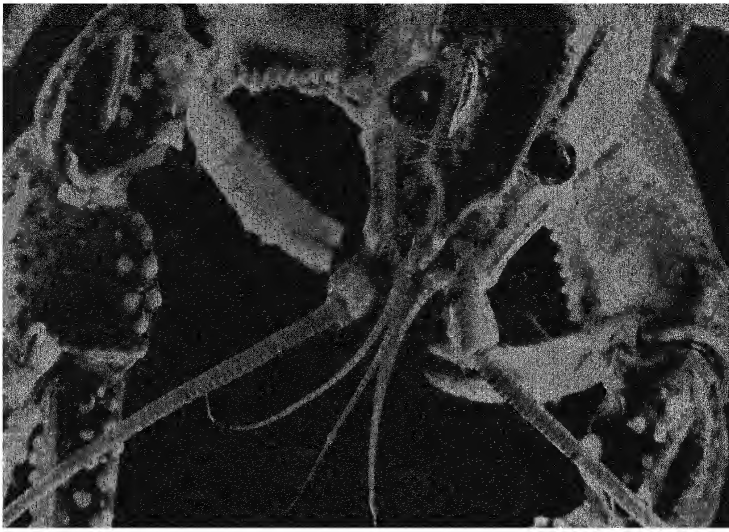
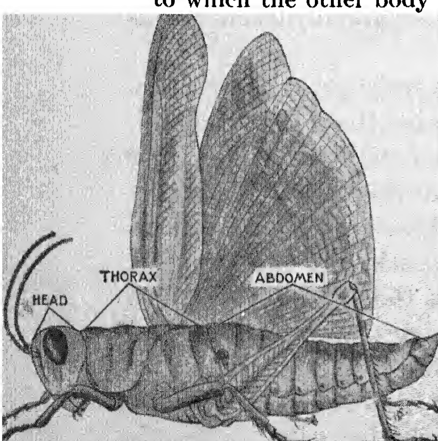


FIG. 103. This picture shows some of the jointed appendages of the crayfish. (P. S. Tice photo)

chitin, that serves as protection. If you will feel the back of a crayfish or a beetle in which this skeleton is well developed, you will understand better the nature of this hard external skeleton. This skeleton serves as a framework to which the other body parts may be attached.



the grasshopper's body

In one way an arthropod is similar to a worm: Its body is segmented, that is, made up of sections. As a rule, there are three sections, or regions, to the body of an arthropod: the head, the thorax, and the abdomen. In some animals the head and thorax grow together, which makes it harder to distinguish the different regions.

Self-Testing Exercises

1. In what ways are all arthropods alike?
2. Name several arthropods.

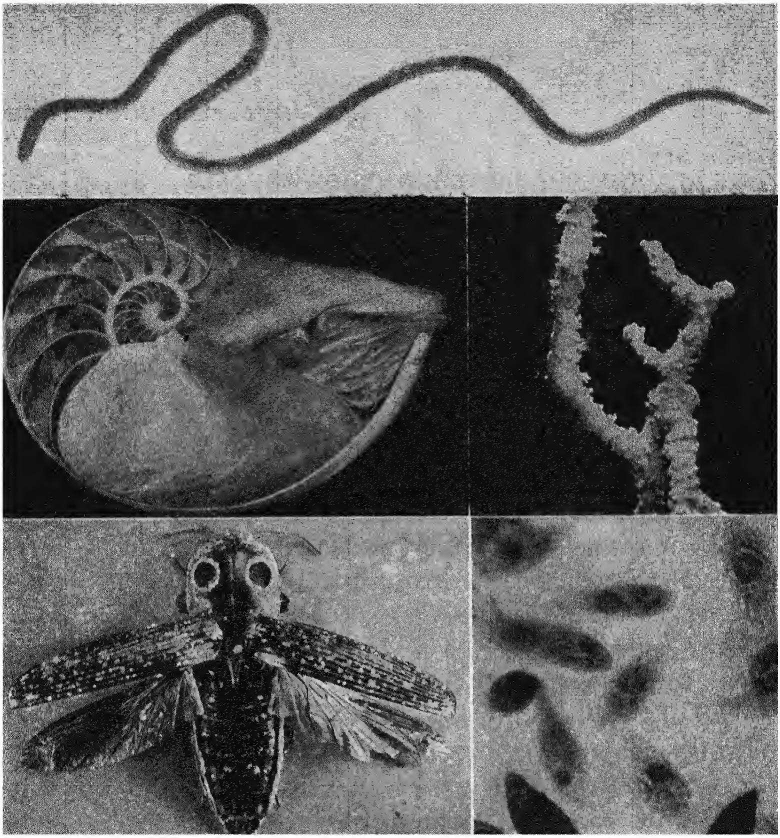


FIG. 105. At the top is a Polychaet worm. In the middle, left to right, are a nautilus and a "precious" coral. At the bottom are a click beetle and several Euglenas.

Problems to Solve

1. In your notebook make a table like the one below and fill it out for each group of invertebrates you have studied.

CHARACTERISTICS OF INVERTEBRATES

Name of Group	Important Characteristics
Protozoa	One-celled animals
Porifera	
Etc.	

2. Classify each animal in Figure 105 as one of a group of invertebrates; that is, name the group to which each belongs. Explain how you know to which group the animal belongs.

Problem 3:
WHAT ARE THE CHARACTERISTICS OF ANIMALS WITH BACKBONES?

If you slide your hand up or down the middle of your back, you can feel your backbone. You can feel that it is not smooth like a rod. As you probably know, the backbone is made of many small bones, or *vertebrae*. Inside the backbone is your main nerve cord, or spinal cord. Nerves branch off from the spinal cord through openings between the vertebrae and go to the muscles that move the body. Nerves from sense organs in your body pass in through the openings between the vertebrae and join the bundle of nerves that carry messages to the brain. Other nerves reach the brain through holes in the skull.

All vertebrate animals are constructed in this way. Invertebrate animals have no backbones. When nerve cords are present, they are on the lower side of the animal instead of the back or upper side. You also breathe through openings that are connected with the upper end of your digestive tube. No invertebrates, except a few close relatives of the vertebrates, have their breathing organs connected with the front end of the food tube. All vertebrates are classified by scientists as *chordates*. In addition to the vertebrates, the chordates include a few animals that have no backbones but have their nerve cord and breathing organs arranged as they are in vertebrates.

When you studied the simpler animals in Problem 2, you found that they lack many of the organs that we have. Some have no nervous or digestive or circulatory systems. Others have simple systems for carrying on body activities. The vertebrate animals all have well-developed digestive, circulatory, nervous, respiratory, excretory, muscular, and reproductive systems. Of course, some details of the systems are different in different animals.

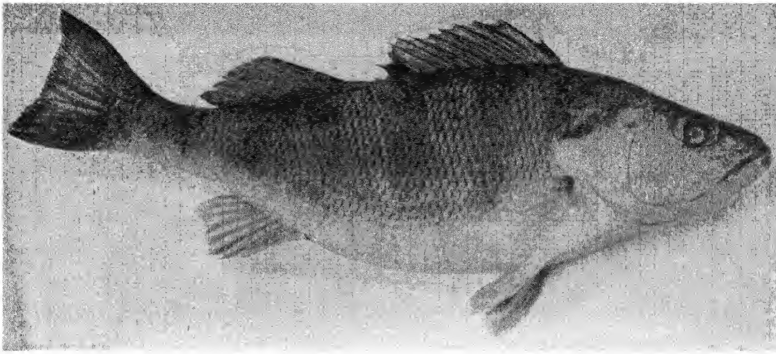


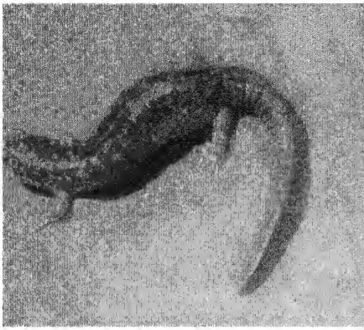
FIG. 106. This yellow perch shows the distinguishing characteristics of fish—fins, gill covers, and scales. (Chicago Museum photo)

When we classified the simpler animals, it was necessary to describe many of the details of structure in order to see how one group differed from another. Furthermore, you knew little about these animals; therefore we had to give you enough facts about the animals so that you could tell something about their general plans of structure. You already know a great deal about vertebrate animals. For this reason, we will tell you only the main characteristics that are necessary to classify these animals.

The vertebrates may be divided into five major classes: fish, amphibians, reptiles, birds, and mammals. You will now study the main characteristics of each of these classes.

WHAT ARE THE CHARACTERISTICS OF FISH? As you know, fish are *aquatic* animals, that is, they live in water. Their structure must be such that they can move about, and they must be able to get a supply of oxygen from the water. Fish usually breathe by means of delicate fringe-like gills. They draw in water through their mouths, and the water passes over the gills. In the gills the blood receives oxygen and gives out carbon dioxide to the water. Then the water passes out through openings at the side of the fish. Fish move by means of a broad tail. They usually have four fins arranged in two pairs.

Most fish have scales over their fins and bodies, and they are *cold-blooded* animals; that is, they do not have the



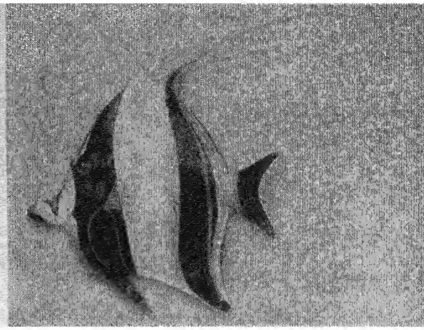


FIG. 107. This salamander is an amphibian found in Texas (Brownell photo)

FIG. 108. The Moorish Idol is a queer-looking fish found in the South Pacific. (Chicago Museum photo)

same temperature at all times. Their body temperature is about the same as the water in which they are living. When the water is cold, they are cold. When the water is warm, they are warm.

WHAT ARE THE CHARACTERISTICS OF AMPHIBIANS? You can guess what one characteristic of an amphibian is if you know anything about frogs. You know that when they hatch from eggs, they become "tadpoles." In this stage of their development they look like fish and act like fish. They have long tails, and they breathe by means of gills. Later on they lose their tails, develop legs and lungs, and are able to come out on the land. All amphibians begin life in the water and usually take to the land when they become adults. They are cold-blooded animals, too. To this class of animals belong frogs, toads, tree-frogs, or "peepers," salamanders, and mud-puppies.

WHAT ARE THE CHARACTERISTICS OF REPTILES? Ordinarily when you speak of a reptile, you are thinking of a kind of snake. A snake is a reptile, but turtles, crocodiles, alligators, and lizards are also reptiles. Reptiles have scales or bony plates developed from the skin. They differ from the fish and the amphibians in this way: In no stage of their life do they breathe by means of gills. They always breathe by means of lungs, which means

that even those reptiles that live in water must come to the surface for air. They also are cold-blooded animals.

WHAT ARE THE CHARACTERISTICS OF BIRDS? Everyone can recognize birds. Birds are the only animals that are covered with feathers. All birds breathe by means of lungs, and, in contrast to fish, amphibians, and reptiles, they have a high body temperature. Their temperatures range from 100° to 110° F. Birds and mammals (which you are to study next) are *warm-blooded* animals; that is, they keep an almost even body temperature, regardless of the temperature of the air or water that surrounds them.

WHAT ARE THE CHARACTERISTICS OF MAMMALS? Bats, whales, seals, elephants, tigers, monkeys, cows, kangaroos, moles, rats, squirrels, and man belong to the class of mammals. These animals are widely different in appearance and widely different in their habits.

Three characteristics distinguish mammals from all other animals: (1) They possess milk glands to feed their young. (2) They possess hair either all over the body or on some part of the body. (3) They possess a diaphragm that divides the interior body cavity into two parts, one of which contains the heart and lungs and the other, the stomach and intestines. Now you can see why a whale is not a fish, and a bat is not a bird. Whales and bats both have all three of the characteristics mentioned above.

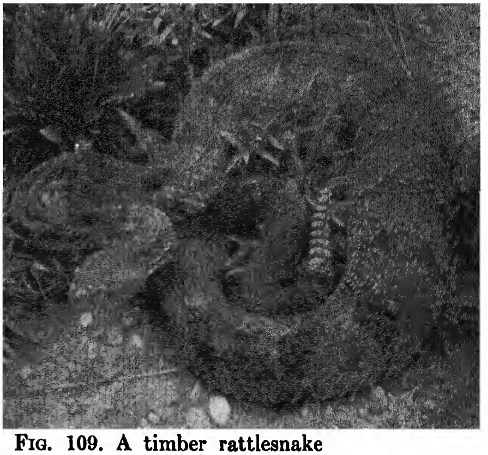


FIG. 109. A timber rattlesnake ready to strike (Brownell photo)

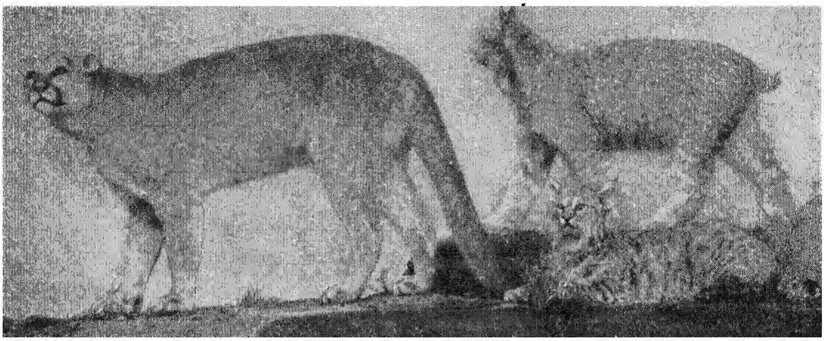


FIG. 110. These mammals are all members of the cat family. At the left is a mountain lion, also called the puma or cougar. At the right top is a bobcat, or lynx. Lying down is a wildcat, or catamount. Tigers, lions, leopards, and cheetahs are also members of the cat family. (Chicago Museum photo)

The study of mammals completes your study of the groups of animals. In your study you started with the simplest animals, and you have worked your way through to the highest group of animals, the mammals. As you have learned, animals vary widely in their plan of structure. It is this different plan of structure among the thousands of kinds of animals in the world that enables the scientist to classify animals into groups of similar kinds. When a scientist knows to what group an animal belongs, he immediately knows many facts about the animal.

This plan of classification has other advantages, some of which you will discover in later units of this book. Among other things, the plan has helped scientists to understand how life has probably developed on the earth. Knowing the classification of plants and animals also helps in the development of new and better kinds of plants and animals, as you will learn when you study Unit 10.

Self-Testing Exercises

1. Copy in your notebook the table at the top of the next page and fill it in for the groups of vertebrates you have studied.

CHARACTERISTICS OF VERTEBRATES

Class	Important Characteristics	Two Examples
Fishes..................	Breathe by gills, etc.	
Amphibians		
Reptiles..................		
Birds..................		
Mammals		

2. How can you tell an amphibian from a fish?
3. How can you tell a reptile from an amphibian?
4. How do birds differ from all other vertebrates?
5. How do mammals differ from all other vertebrates?

Problems to Solve

1. What kinds of mammals lay eggs? Read about the duck-bill, or platypus, and the spiny ant-eater.

2. What mammals were once thought to be fish? How do we know that they are not fish? Read about whales and dolphins.

3. What are some of the common groups of mammals? Read about rodents, carnivores, insectivorous animals, hoofed animals (ungulates), pouched animals (marsupials), and flying mammals (bats).

4. Why do scientists know the horned toad is a reptile and not an amphibian? Read about the horned toad and apply your knowledge of the characteristics of reptiles and amphibians.

5. Lizards and salamanders seem somewhat alike to most people. How do scientists know that they belong in different classes of animals?

6. How do reptiles reproduce? Read about alligators, snakes, and turtles. Compare their methods with those of amphibians, birds, and mammals.

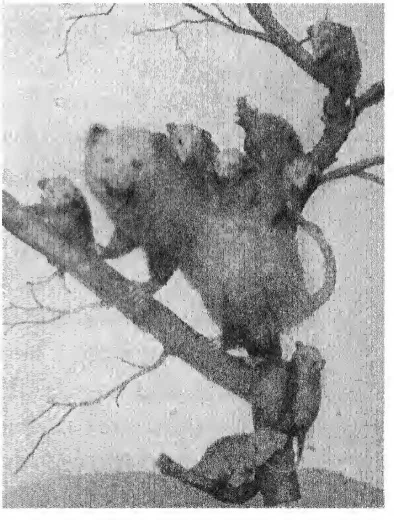


FIG. 111. Opossums are marsupials found only in the United States. (Chicago Museum photo)

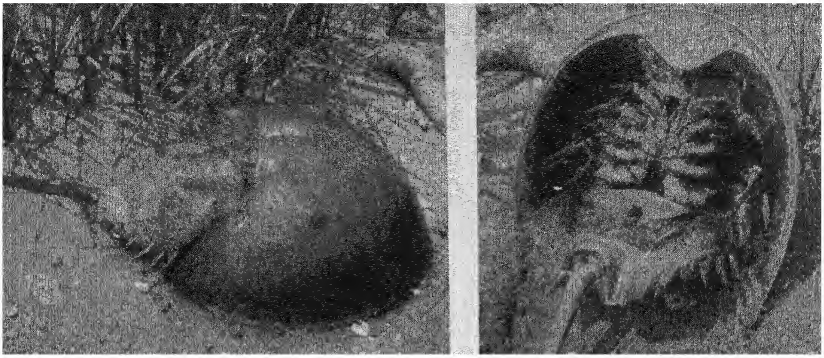


FIG. 112. The horse-shoe crab (*Limulus*) is an arthropod belonging to the class Crustacea. (L. W. Brownell photo)

Problem 4:

WHAT PLAN OF CLASSIFICATION DOES THE SCIENTIST USE?

IN PROBLEM 1 you learned something about the way in which a scientist classifies animals. In Problem 2 you studied the great groups of animals that have no backbones, and in Problem 3 you studied the animals that have backbones. You saw that the animals of each group have certain characteristics that are alike, and that the animals of each group have certain characteristics that are unlike those of the animals in other groups.

In this problem we will see in detail how the scientist classifies animals. You will see that the names are either Greek or Latin or a mixture of these languages. Greek and Latin words are used because early scientists used these languages and because of the confusion that arises from common words. The name chosen for an animal usually describes it in a general way. In the pages that follow, you will find the English translation of most of the terms used.

Each of the large groups of animals is called a *Phylum* (plural *Phyla*). For example, in speaking of the group of one-celled animals, the scientist would say that they belong to the Phylum Protozoa. The hydra belongs to the Phylum Coelenterata, the earthworm to the Phylum Annelida, and so on. The accurate separation of animals

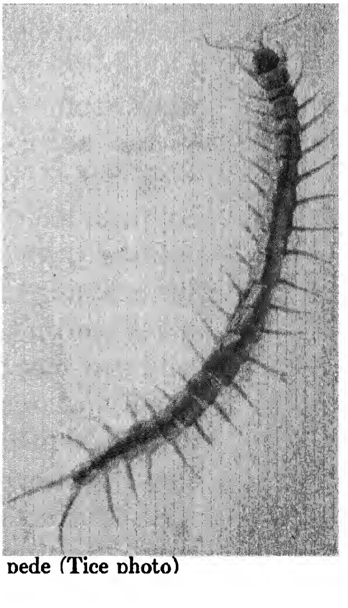
into different phyla is the result of hundreds of years of patient study by many different scientists.

In this problem you are going to see how a phylum is divided into smaller and smaller groups of animals. As an illustration we will take the Phylum Arthropoda. Since there are over 500,000 different kinds of animals belonging to this phylum, you can see the necessity for further classification of its members. Let us first summarize briefly the main characteristics of this phylum. Every animal in the phylum has the following general characteristics:

Phylum Arthropoda. Jointed legs, antennae, and other appendages; hard external skeleton; three regions of body—head, thorax, and abdomen, these regions being fused in some animals.

The next smaller division in the plan of classification is the *Class;* that is, the phylum is divided into classes. The animals in each class have certain characteristics that distinguish them from animals in other classes. A description of each class in the Phylum Arthropoda and of the members of each class follows:

Class 1. Crustacea (shelled animals). Live chiefly in the water; breathe by means of gills or through the body wall; head and thorax usually united and covered with a part of the external skeleton; always have more than four pairs of legs; movable eyes located on the ends of stalks; compound eyes. The class Crustacea includes, among other animals, crayfish, crabs, barnacles, lobsters, shrimp, and sowbugs.



pede (Tice photo)

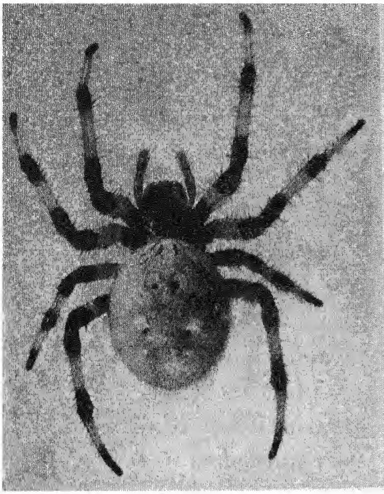


Fig. 114. Common garden spider found in the Middle West (Tice photo)

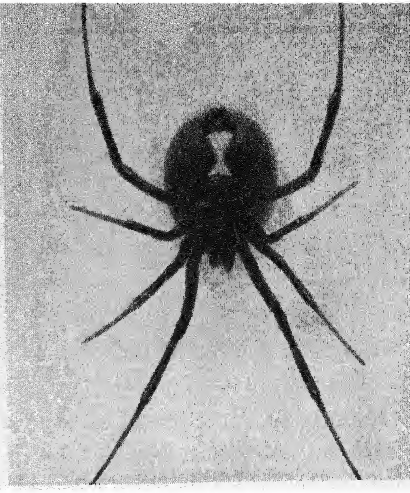


Fig. 115. On the underside of the black-widow spider there is a red mark resembling an hour-glass. (Passmore photo)

Class 2. Myriapoda (*many-legged animals*). Worm-like form; segments numerous and much alike; one or two appendages to each segment; simple eyes. This class includes centipedes, millipedes ("thousand-leggers").

Class 3. Insecta. Three pairs of legs; one or two pairs of wings (some forms have no wings); three distinct regions of the body—head, thorax, and abdomen; compound eyes. This class includes flies, butterflies, beetles, grasshoppers, etc.

Class 4. Arachnida. Four pairs of legs; no wings; simple eyes; no antennae. To this class belong the spiders, tarantulas, scorpions, daddy-long-legs, and ticks.

If you find an animal in the water or air that you can classify as an arthropod, you can now go one step farther in its classification. By means of the description given above, you can identify it as a member of a certain class.

Scientists have studied the members of each class and have discovered characteristics that help to divide each class into *orders*. For example, the class *Insecta* is divided into twelve orders, each of which has characteristics

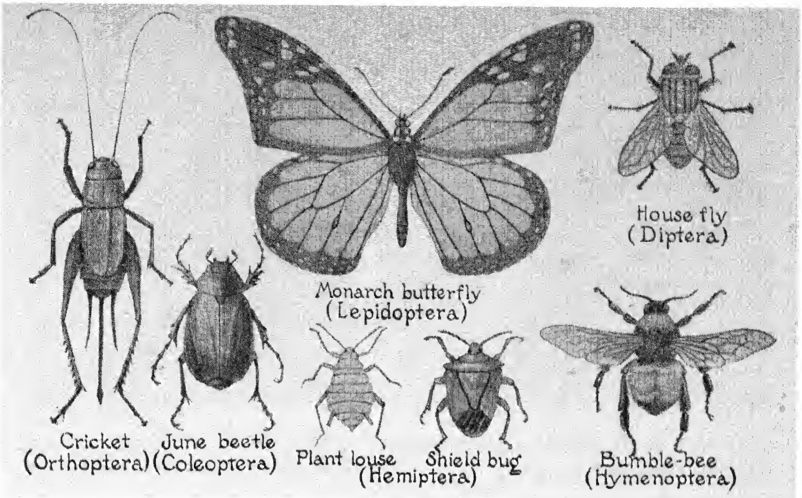


Fig. 116. These insects represent the principal orders into which the class *Insecta* is divided.

different from all other orders. A description of the principal orders of the class Insecta follows:

Order Hymenoptera (*membranous wings*). Four similar thin wings, of which the front pair is the larger. *Examples:* ants, bees, wasps, and gall insects.

Order Coleoptera (*sheath wings*). Hard outer wings meeting in the middle of the back, forming a cover for a second pair of wings underneath. *Example:* beetles.

Order Lepidoptera (*scale wings*). Four wings covered with scales. *Examples:* butterflies and moths.

Order Orthoptera (*straight wings*). Leathery and straight front wings; net-veined rear wings. *Examples:* grasshoppers, locusts, crickets, cockroaches, and walkingsticks.

Order Hemiptera (*half wings*). Two pairs of wings or none; piercing and sucking mouth parts. *Examples:* true bugs, lice, and plant lice.

Order Diptera (*two wings*). Most seem to have only two wings. The fore wings are developed, and the hind wings are reduced to knobs. *Examples:* flies and mosquitoes.

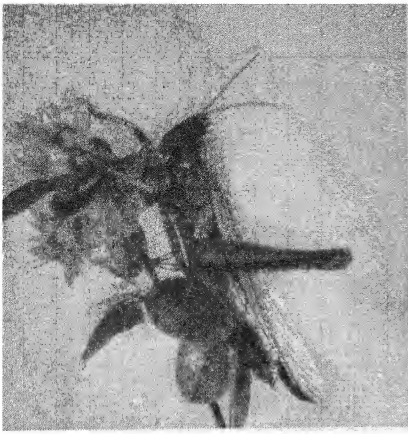


FIG. 117. A Rocky-Mountain locust (L. W. Brownell photos)

FIG. 118. A red-legged locust. Compare with the other locust.

An order may be divided still further into *families*. For example, the order Orthoptera includes the cockroach and the locust. If you know these two insects, you can readily see that one has certain characteristics not possessed by the other. The cockroach belongs to the family *Blattidae*, all of whose members have three pairs of legs that are similar in form and bodies that are oval-shaped. The locust belongs to the family *Acrididae*. Members of this family have hind legs that are much longer and stouter than the middle pair.

Each family may be sub-divided still further into *genera* (singular, *genus*). Finally, a genus is divided into a number of *species* (singular, *species*). Usually one species in a genus is only a little different from another species in the same genus. When an animal has been classified in a certain genus and species, we know its scientific name. The scientific name of an animal is made up of the name of its genus and the name of its species. The name of the genus always comes first.

The name of the common red-legged locust is *Melanoplus femur-rubrum*. *Melanoplus* is the name of the genus, and *femur-rubrum* ("red-legged") is the name of the species, or particular kind of grasshopper. Another kind

very much like the red-legged locust has the name *Melanoplus spretus*. Thus we know that it has been classified in the same genus but is a different species.

And now let us review briefly the scheme of classification used by the scientist as illustrated by the red-legged locust.

Kingdom—Animal
Phylum—Arthropoda
Class—Insecta
Order—Orthoptera
Family—Acrididae
Genus—Melanoplus
Species—Femur-rubrum

In classifying a given animal, we first decide upon the phylum, then the class of the particular phylum, then the order of the class, then the family, then the genus, and finally upon the particular species. When you consider that there are over 600,000 known species of animals, each with its own name, you can appreciate what a tremendous task it has been to discover a scheme that would work, and then to study the structure of each animal so carefully that a description could be made to distinguish it from all other animals.

Self-Testing Exercises

1. How can you tell the difference between an insect and a spider?
2. In what ways are all arthropods alike?
3. What characteristics are used to divide the class Insecta into orders?
4. What does the scientific name of an animal tell us?
5. Write the following names of groups in their correct order, beginning with the smallest group and ending with the largest: class, family, genus, kingdom, order, phylum, species.

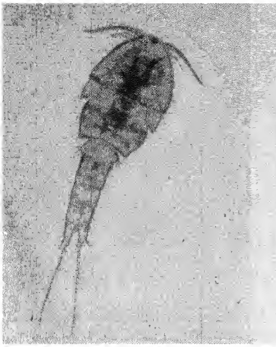


FIG. 119. Cyclops, a microscopic crustacean (Hugh Spencer photo)

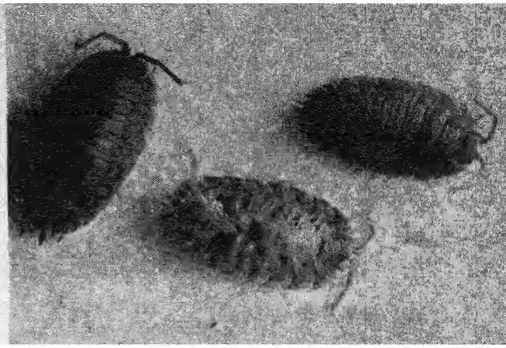


FIG. 120. Sow bugs, or pill bugs. These are crustaceans that are found on land. (Cornelia Clarke photo)

Problems to Solve

1. Obtain as many different kinds of leaves as you can. Make up a scheme of classifying them. Then give your scheme of classification to someone and see if he can identify leaves by your plan.

2. In some book that classifies animals or plants find the names of the genera and species of some common animals or plants. Can you find several species that belong in one genus, several genera that belong in one family, etc.?

3. Can you classify insects? Catch a number of insects. Kill them by putting a drop or two of gasoline on each one. Then try to classify each specimen in one of the orders on page 125.

4. How many arthropods can you find that are not insects? Look under damp boards or rotting logs for pill bugs and in ponds and streams for crayfish. Fish among water plants with a kitchen strainer or a piece of screen wire for "benders." A number of water plants carried home in a can and put in a glass jar, fish bowl, or aquarium with plenty of water will almost always contain a number of crustaceans so small you will need a microscope to see their jointed legs. Most of these small animals are transparent, and you can see their internal organs with the low power of a microscope.

Look also for spiders, daddy-long-legs, and hundred-legged-worms. Notice that each of these has the characteristics of the arthropods. Classify each one as a crustacean, a myriapod, or an arachnid.

Problem 5:

WHAT ARE THE DIFFERENT KINDS OF PLANTS?

WHEN you started your study of this unit, you were asked to make a list of the plants that you know. How many plants did you name? Very few people can name a hundred different kinds of plants. Scientists, however, have discovered and named about 225,000 different kinds. With such a large number of plants you can see that it is necessary to classify them so that they may be studied.

Of course, the characteristics that you look for to classify plants are quite different from those used to classify animals. However, the structure of some plants is very different from the structure of other plants. Because of differences in their structure and in their methods of reproduction, plants can be classified into four groups, *thallophytes*, *bryophytes*, *pteridophytes*, and *spermatophytes*.

WHAT ARE THE CHARACTERISTICS OF THE THALLOPHYTES? If you will look on the north side of trees in shady and damp places, you will find places where the bark is green, as if it had been stained. If you scrape off a little of this green material, place it in a drop of water, and examine it under the microscope, you will see that it is made up of many tiny one-celled plants (Figure 121). Some of the cells are joined with other cells to make colonies.

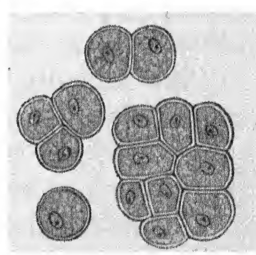


FIG. 121. Pleurococcus

The name of this plant is *Pleurococcus*. Inside of each cell is some green coloring material, chlorophyll. You see that the plant has no roots, stems, or flowers. The plant is all body. The word "thallophyte" means a plant that is all body.

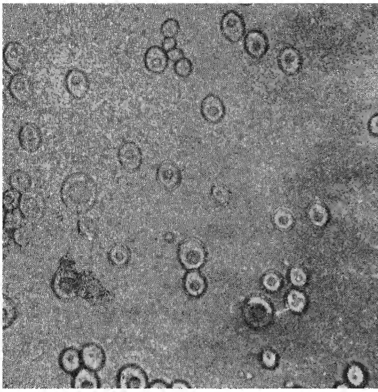


FIG. 122. Yeast plants, as they look under a microscope (Century photo)

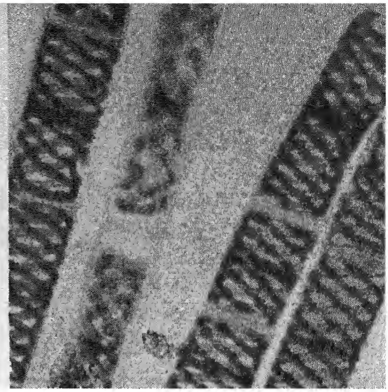


FIG. 123. Spirogyra, an alga having spiral chlorophyll bodies in its cells (Hugh Spencer photo)

Suppose your mother told you to go to a grocery store and bring back a few million plants. What would you ask the grocery man for? Do you think you would have much trouble in carrying this number of plants? You would not if you asked for a cake of yeast. A cake of yeast does not look as if it were made up of millions of plants. But put some of the yeast in a solution made of a little sugar and water for a few hours and then examine a drop of the solution under the microscope. You will find many tiny and almost colorless cells (Figure 122). These cells are really plants, and they are thallophytes. Unlike the pleurococcus, they have no chlorophyll.

The thallophytes are divided into two groups, according to whether they have or do not have chlorophyll. The *algae*, such as pleurococcus, have chlorophyll, and the *fungi*, such as yeast, do not have chlorophyll.

One of the commonest algae is *Spirogyra*, which is often found in watering-troughs, ponds, and streams. It looks like a mass of green material floating in the water. Some people call it pond scum. If you will get a small mass of this material and look at it closely, you will see that it is composed of a large number of small green threads. Under the microscope you can see that each green thread is

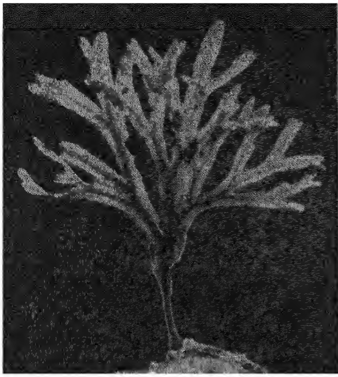


FIG. 124. This olive-green alga is found in masses on rocks at low tide. (Spencer photo)

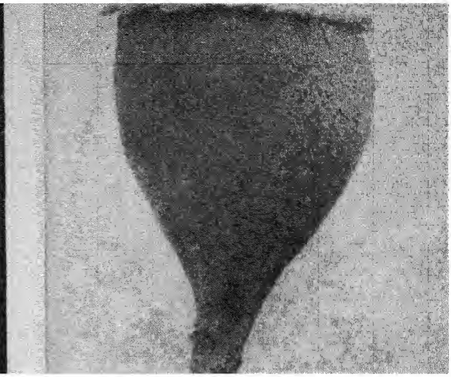


FIG. 125. This brown fungus has an interesting urn-like shape. (Cornelia Clarke photo)

made of a single row of cells. If the material you have collected is really Spirogyra, each cell will contain one or more spiral bodies that have chlorophyll in them. This alga gets its name from these spiral chlorophyll bodies.

There are many different kinds of algae. Some of them are merely single cells; others are seaweeds a hundred feet in length. But they are all alike in one way: They have no leaves, stems, roots, or flowers. There are nearly 10,000 different kinds of algae.

You have seen many different kinds of fungi: bread mold, which appears as a mass of white threads on bread; green mold, found on preserves, oranges, and old shoes; and various kinds of mold on decaying fruits. If you live in the country, you have seen brown or black spots on wheat and oats. These are caused by *rust* fungi. You may also have seen blackened ears of corn and heads of wheat caused by *smuts*. Mushrooms, puffballs, and the shelf fungi on trees are other fungi that we often see. Scientists have discovered about 75,000 species of fungi. They vary widely in appearance. Since they have no chlorophyll, they of course cannot make their own food. They must get their food from other plants, from animals, or from materials made by plants and animals. For this reason many of the

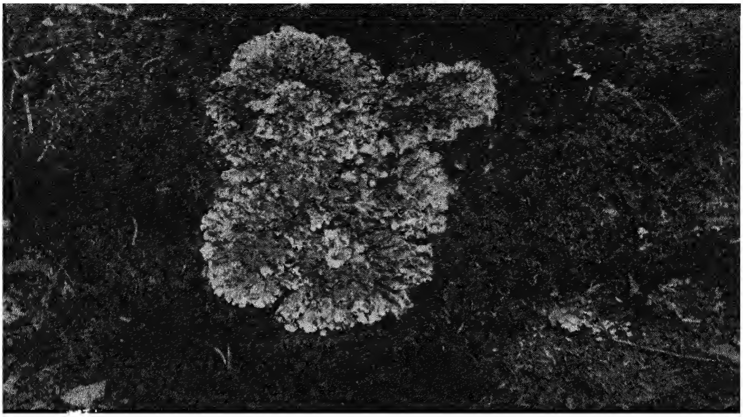
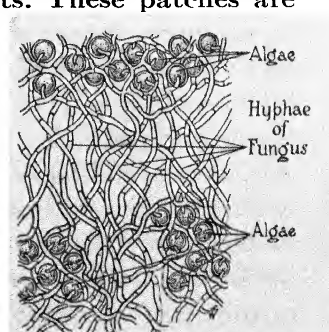


FIG. 126. Lichens grow in several different forms. Some are flat and leafy like the one above. Others are divided into many branches. Still others grow as a very thin crust on rocks or tree trunks.

fungi are harmful. Fruit-growers and doctors study fungi and try to find ways to fight them.

In addition to the plants just described, there are the tiny one-celled fungi known as *bacteria*. As you learned in *Book 2*, some bacteria attack human beings and cause disease. These are called disease germs. Many kinds of bacteria are quite useful in making butter, vinegar, and other valuable products.

Often you will find patches of gray, green, or brown on rocks, trees, or even fence posts. These patches are *lichens*. They can grow where no other plants can grow. Scientists used to believe that a lichen was a single plant, but they have since discovered that a lichen is composed of two kinds of plants, an alga and a fungus. Examined under a high-power microscope, part of one appears as shown in Figure 127. Living together, it is possible for these plants to grow where neither one could live alone. The



surrounded by the hyphae of the fungus.

FIG. 128. The light bodies of this hair-cap moss are capsules that bear spores for reproduction. (L. W. Brownell photo)

fungus absorbs what little water is available and protects the algae from extreme dryness. The algae manufacture food that the fungus obtains by sending tiny branches into the algae. Both plants are thus helped by their partnership.

WHAT ARE THE CHARACTERISTICS OF THE BRYOPHYTES? The plants known as bryophytes ("moss plants") include two classes, the *mosses* and the *liverworts*. These plants never grow more than a few inches tall and are usually found in moist places or in water. The stems and leaves of mosses are not true stems and leaves, because they do not have a vascular system or stomata (*Book 1*, pp. 320-324). Neither do the mosses have true roots. They have thread-like structures, called *rhizoids*, that grow down into the soil. These serve the same purpose as roots, but their structure is so simple that they cannot be classed as roots. Figure 351 in *Book 2* showed you the many-celled structure of a true root. The rhizoids of some of the bryophytes appear more like the root-hairs, since they are just one elongated cell. Other rhizoids are filaments consisting of a single row of cells.

Until you study liverworts quite thoroughly, it is difficult to see why they are placed in the same group with the

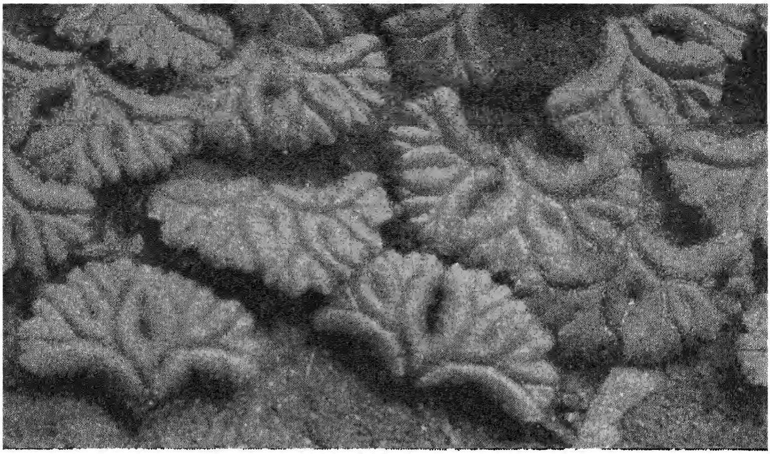


FIG. 129. There are many kinds of liverworts found all over the world in damp and shady places. (L. W. Brownell photo)

mosses. The liverworts have flattened bodies that are often branched (Figure 129). Extending from the lower surface are the rhizoids that penetrate the soil to obtain water. Some of the liverworts, however, are so much like mosses that only an expert can tell to which class they belong.

WHAT ARE THE CHARACTERISTICS OF THE PTERIDOPHYTES? You are already acquainted with ferns. Ferns form one class of pteridophytes ("fern plants"). They are usually recognized by their greatly divided leaves. The ferns have true leaves, stems, and roots, and a well-developed system for conducting water up from the roots to the leaves and food down from the leaves to the roots. One set of tubes carries the water up, and one set carries the food down. These sets of tubes together make up the vascular bundles and extend from the roots into the leaves. Because of these vascular bundles pteridophytes can grow to a much greater size than the bryophytes. As you know, ferns reproduce by means of spores. On the backs of fern leaves you can often find the little brown spots where the spores are produced.

Another class of the pteridophytes includes the horsetails, or "scouring rushes," and another class the club

FIG. 130. Ferns vary greatly in size. The tree ferns, like these that grow in Hawaii, reach a height of forty feet. However, most kinds are smaller. (Courtesy K. C. Hamner)

mosses. These plants also possess true leaves, roots, and stems, and they reproduce by means of spores.

WHAT ARE THE CHARACTERISTICS OF THE SPERMATOPHYTES? The highest group of plants includes those that bear seeds. This is the characteristic that distinguishes the spermatophytes ("seed plants") from the other three groups. Spermatophytes also have true leaves, stems, and roots. The vascular bundles are well developed, and these plants may grow to tremendous size.

FIG. 131. The cone-like structures of the horsetail bear spores. (L. W. Brownell photo)

The spermatophytes are divided into two sub-groups, *gymnosperms* and *angiosperms*. Pine, cypress, hemlock, spruce, and cedar are common gymnosperms. In these plants the seeds are borne in *cones*. The angiosperms bear flowers, in which the seeds grow. It is thus very easy to tell a gymnosperm from an angiosperm. At the present time

FIG. 132. The pine cones at the right have opened and dropped the seeds to the ground. (L. W. Brownell photo)

about 140,000 different kinds of spermatophytes have been discovered and named.

The angiosperms are divided into two classes, the monocotyledons and the dicotyledons. As you learned in *Science Problems, Book 2*, the monocotyledons are plants whose embryos have one cotyledon, and the dicotyledons are plants whose embryos have two cotyledons.

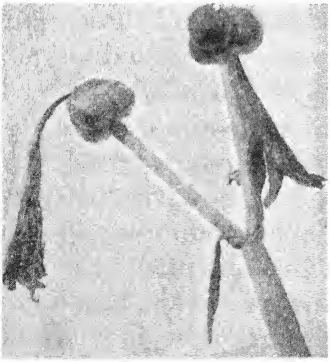


FIG. 133. The seeds of angiosperms are concealed within the fruit.

These two classes may be identified by other characteristics. The monocotyledons have: (1) usually parallel-veined leaves, like those of the lily and grass; (2) flower parts arranged in groups of three; (3) vascular bundles that are scattered throughout the stem. The monocotyledons include such plants as wheat, corn, rye, oat, barley, wild grasses, bamboo, date palm, hyacinth, tulip, asparagus, onion, lady's slipper, pineapple, and banana.

FIG. 134. Is the trillium a monocotyledon or a dicotyledon? What can you see in this picture that would help you decide?

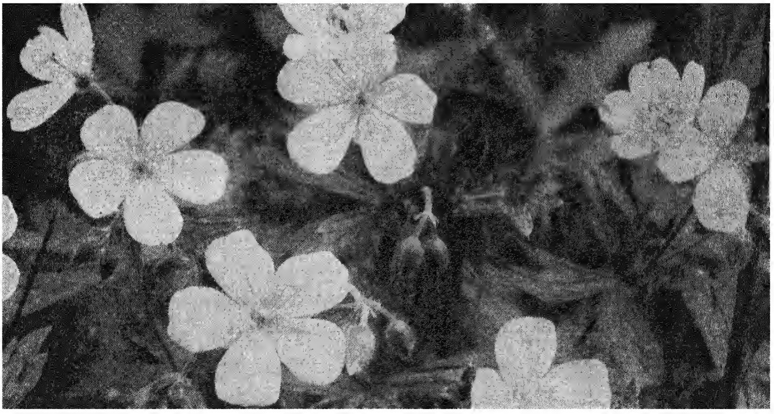


FIG. 135. Is the wild geranium a monocotyledon or a dicotyledon? How do you know? (L. W. Brownell photos)

The dicotyledons have: (1) netted-veined leaves, like those of the elm and oak; (2) flower parts arranged in groups of four or five; (3) vascular bundles arranged in a definite ring of growing tissue. The dicotyledons include such plants as the pea, bean, rose, apple, peach, pear, strawberry, cabbage, turnip, willow, carrot, sunflower, dandelion, oak, and maple.

Self-Testing Exercises

1. Copy the following table and insert "Yes" or "No" in the columns.

CHARACTERISTICS OF PLANT PHYLA

Phylum	True Roots, Stems, and Leaves	Vascular Bundles	Seeds
Thallophyte			
Bryophyte			
Pteridophyte			
Spermatophyte			

2. How can you distinguish a thallophyte from all other phyla?

3. How can you tell a bryophyte from a pteridophyte?

4. What characteristic distinguishes a spermatophyte from all other phyla?

LOOKING BACK AT UNIT 2

1. How has this unit helped you to understand better the world in which you live?

2. What can you do now that you could not do before you studied this unit?

3. A number of important science words have been used in this unit. Be sure that you know what they mean, so that you can use them intelligently. Give the meaning of each word below:

cilia	*mammal*	*tentacle*
classify	*phylum*	*vertebrae*
cold-blooded animal	*rhizoid*	*vertebrate animal*
invertebrate animal	*structure*	*warm-blooded animal*

ADDITIONAL EXERCISES

1. In Introductory Exercises 3 and 4 you made a list of the plants and animals that you know. Classify each of these plants and animals in the phylum to which they belong. If you can, classify them as to class also. An encyclopedia or books on botany and zoölogy will help you to do this.

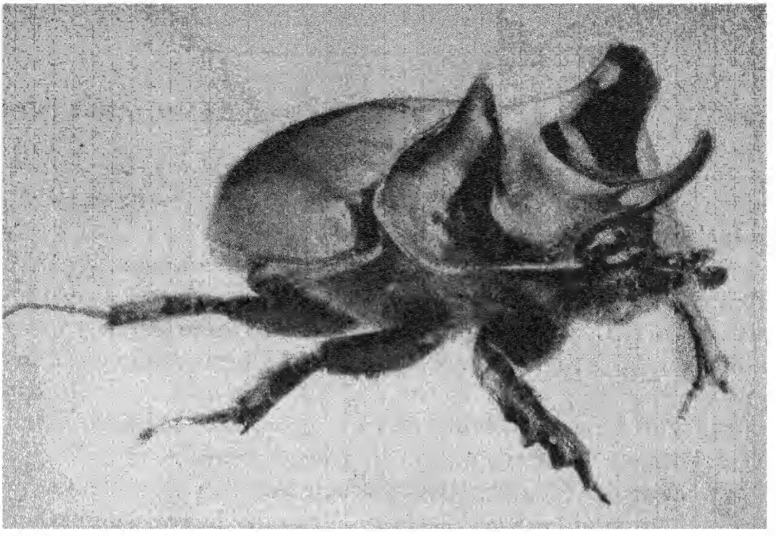


FIG. 136. By now you know that animals have many unusual shapes. You can readily see why this one is called a rhinoceros beetle. To what phylum, class, and order does it belong? (P. S. Tice photo)

2. How would you go about classifying a plant or an animal that you had never seen before?

3. Which of the phyla of animals include animals that are valuable to man?

4. Which of the phyla of animals include animals that are dangerous to man?

5. Worms, caterpillars, and snakes look somewhat alike. Why would you classify them in different phyla?

6. What orders of insects contain species that are especially harmful in your region? Read in reference books about harmful insects and find out to which group each insect belongs. This will not be hard when you know the characteristics of the most important orders of insects, as given on page 125.

7. How many kinds of mosses or ferns can you find? Mosses can be kept growing very nicely in covered fish globes, butter dishes, etc. However, they will often be attacked by fungi if kept too wet. Fern leaves may be pressed in an old magazine or book. If you are a persistent, careful worker, you can learn to classify ferns by using a key in a book. Ask your teacher or a librarian for help.

8. If you have a microscope to use, see how many kinds of algae you can find. Botany books may be helpful in classifying some of the algae you find.

9. How do the life histories of plants help to classify them? Read in botany or biology books about the life history of a moss, a liverwort, and a fern. From the facts you learn tell why mosses and liverworts are classified together and ferns are in a different group.

10. Tell how the plants of each group are helpful to man. Which groups contain plants that are harmful?

11. Learn to identify trees by their leaves. Collect leaves and press them in old magazines or books under heavy weights until they are quite dry. Then fasten them on the pages of a suitable note-book. Use the "key" in a tree book to identify the leaves of trees you do not know. You may need to have some older person help you.

12. Make a collection of the common weeds in your neighborhood and learn to know them by their names. Leaves or small plants with their roots may be pressed and fastened in a note-book as directed in Problem 11.

FIG. 137. Jumping a ten-foot ditch is easy for these three kangaroos. Their long hind legs and strong tails help them speed over the ground in great leaps, often as long as fifteen feet. In their homes on the open plains in Australia, where it is difficult to hide, this speed helps them escape their enemies. In each of the many other kinds of places on the earth are plants and animals that can live there because they are fitted to the surroundings. (Ewing Galloway photo)

UNIT THREE

UNIT 3

HOW ARE PLANTS AND ANIMALS FITTED TO THE CONDITIONS AROUND THEM?

INTRODUCTORY EXERCISES

1. Make as long a list as you can of the ways in which water is used by animals.

*2. Why must green plants have light? Explain the reasons briefly.

*3. Name some plants that grow best in the dark.

4. Is it easier for plants and animals to live on land or in water? Give reasons for your answer.

*5. Do both plants and animals need soil? Explain your answer.

*6. What kind of place is necessary if living things are to exist? That is, what do you think are the conditions and materials absolutely necessary for life to continue? Take both plants and animals into consideration as you prepare your answer.

7. How are the plants that live in a desert different from those that live in a forest? Do you think these differences help the plants to live? Why?

8. (*a*) Name three animals that live only in water. (*b*) How are these water animals different from those that live on land? Make a list of differences.

9. Give three examples of ways in which plants protect themselves from animals.

10. How is man well fitted to his surroundings? How is he poorly fitted?

*11. Make a list of some of the ways in which animals are fitted for getting and using food.

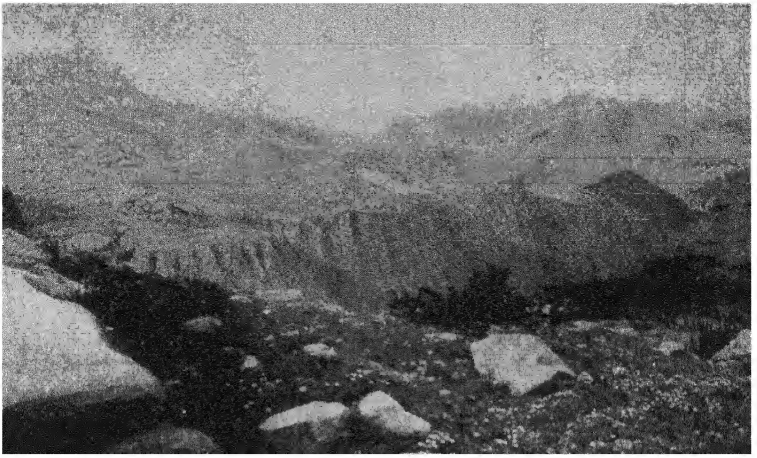


Fig. 138. We see flowers and snow at the same time in this meadow high on a mountainside, above the line where trees will grow. These plants can grow here in such abundance because they are especially fitted to live in these surroundings. (Chicago Museum photo)

LOOKING AHEAD TO UNIT 3

Do you ever expect to see a fish walk on dry land? If you were chasing a squirrel in the woods, would you expect it to jump into a pond and lie hidden under the water until you left? Would you expect to find a green frog a mile from any water? If you live in the northern part of the United States, would you expect to find a palm tree growing in the woods? Did you ever see a chicken walk into the water and start swimming around? Would you expect to find a banana tree growing on top of a high mountain or ferns growing in the middle of a desert?

If you answered "no" in reply to each of these questions, you were correct. You probably had no difficulty in answering the questions correctly. Suppose, however, that someone disagreed with you. Could you give a reason for your answer in each case? For example, why do you never expect to see a fish walking on dry land? You might say, "A fish cannot get food on dry land because it cannot move around. It cannot live on dry land because it cannot get oxygen from the air." These would be good reasons,

FIG. 139. In what parts of the world are monkeys found? Do they live in open plains, deserts, swamp lands, or forests? These baboons live in a zoo, but their surroundings are similar to their rocky native home. (Photo by De Cou from Ewing Galloway, N. Y.)

and perhaps you could also explain why you would not expect to find the other living things in the surroundings mentioned.

Fish do not walk on dry land; squirrels do not hide in the water; palm trees do not grow in the north woods; and banana trees do not grow on mountains. Why not? Because they do not have the kind of structure needed to keep themselves alive in these places. Their bodies are made in such a way that they can keep alive only in certain kinds of surroundings. The structure and the habits of every plant and animal must be fitted, or *adapted,* to the conditions found in the place where the plant or animal lives; otherwise it will die.

When you visit a zoo, you see animals that come from many different places. Some come from the dry desert; others, from the hot, moist tropics; and still others, from the frozen regions of the northland. Have you ever noticed how differently these animals are housed and cared for? The keepers are careful to make their new homes as much

like their natural homes as possible. The penguins and polar bears are given the coolest places, with ponds and streams of cool water in their cages. The desert reptiles have warm, dry places with sand on the floors. The sea animals are put in salt water brought at great expense from the ocean. And each kind of animal is fed the kind of food needed to keep it healthy. The keepers know that each animal is fitted to live amid certain conditions of temperature, moisture, food materials, etc., and these conditions must be provided if the animal is to live.

The place in which an animal lives is called its *habitat.* Let your mind wander all over the world to the different places about which you have read or which you may even have visited. Think of all the different kinds of habitats. There is scarcely a place on earth without its plants and animals, yet how different these places are and how different the plants and animals that inhabit them! There are thousands of miles of dry desert—some hot and some cold; there are the dark depths of the oceans; there are the warm islands of the South Seas and the ever-cold regions of the North and South Poles; there are mountains that rise thousands of feet into the air. Yet plants and animals live in all these places.

But you do not have to wander over the world to find different kinds of habitats. Think about the


you say about conditions for living in this habitat? (Ewing Galloway photo)

place where you live. Are there rivers, creeks, lakes, or swamps near by? Are there high hills, deep forests, and open fields? Each of these is a different kind of habitat, and certain plants and animals that live in one of these places will not be found in the other places because they cannot stay alive in the other places.

Now you already know that every plant and animal must be able to do certain things in order to stay alive. Living things must be able to get oxygen, food, and water; they must be able to reproduce more living things like themselves; and they must be able to protect themselves from their enemies. In Unit 2 you learned that plants and animals are made in countless different ways. The way in which an animal is made, that is, its structure, determines where it can live and how it gets the things it needs to stay alive. In this unit you will learn why an animal or a plant that can live in one place cannot live in another place. You will learn what kinds of structures plants and animals have in order that they may live in different kinds of habitats.

Why is adaptation to habitat so important? You have probably already guessed the answer. Adaptation is a matter of life and death. What happens when we have an unusually hot, dry summer in a place where rainfall is usual? Millions of plants and animals die. What happens when we have a long, cold winter in a place where mild winters are normal? Millions of living things are killed. Cut down the forests and drain the swamps, and you either destroy or drive away countless plants and animals. All these things happen because the conditions of the habitat are changed, and the plants and animals cannot live amid the changed conditions. They must either move out or die.

FIG. 141. Many kinds of water plants and animals live in the swampy Everglades of Florida. Often the water is completely covered with great masses of floating water hyacinth, as shown in parts of this picture. (James Sawders photo)

Problem 1:

HOW ARE ANIMALS AND PLANTS FITTED TO LIVE IN WATER?

BEFORE YOU begin to learn how animals and plants live in water, think about the water habitats that you know best. If you live near the ocean, you will think of salt water with its seaweeds, starfish, and sea-anemones in the pools left by the tide and of lobsters, oysters, and clams. If you live in the mountains, you will imagine the cold mountain streams and lakes. Perhaps you will think of your favorite deep fresh-water lake, of a wide river, of a shallow pond with water-lilies, of a great swamp, or of a deep ocean.

In all of these water habitats the conditions are different in some ways, but in all of them plants and animals are able to get the necessary things for living. Let us see how plants and animals are adapted to water habitats—even to such a habitat as the deepest parts of the ocean, where the conditions are very different from those in other water habitats.

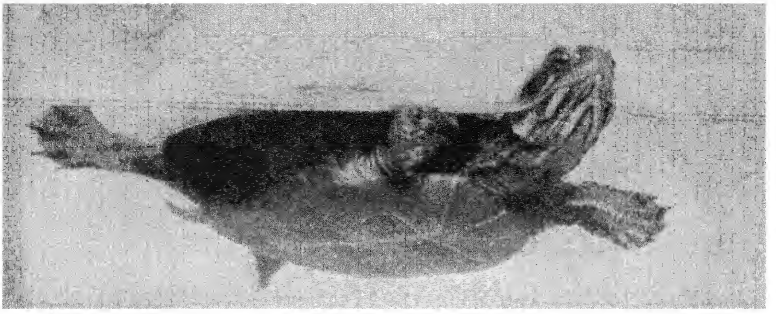


FIG. 142. Although the turtle spends most of its life in water, it breathes by means of lungs and must therefore come to the top for air, except during the winter, when it hibernates in the mud at the bottom. (L. W. Brownell photo)

HOW ARE LIVING THINGS FITTED TO GET OXYGEN FROM THE WATER? One of the great differences between living in water and living on land is the fact that the plant or animal living in water must be able to get its oxygen from the water rather than from the air. The oxygen, as you know, is dissolved in the water. This oxygen simply diffuses (*Book 2*, pp. 368-370) into simpler animals, such as the ameba, the paramecium, and the sponge.

The fish, a more complicated water animal, has gills. These gills are feather-like structures with very thin walls. Using its mouth as a water pump, the fish keeps a current of fresh water flowing in through its mouth and out past the gills. The gills stream backward in the water like curtains in the wind. Between the water and the blood of the fish there is only a very, very thin layer of cells. The oxygen from the water can easily diffuse or pass through these cells into the blood, and carbon dioxide from the blood can diffuse out

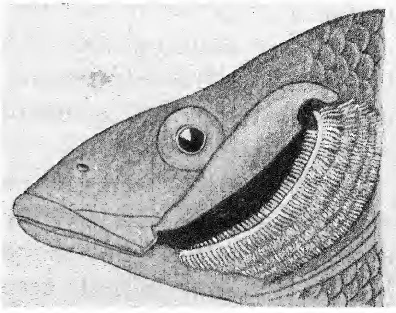


FIG. 143. In this drawing the gill cover is turned back to show the gills.

into the water. The used water keeps flowing away, so that there is always fresh water next to the gills.

One of the curious adaptations for life in the water is shown by the alligator. This animal breathes by means of lungs. It cannot get oxygen through its skin; so it must come to the surface to breathe. In the nostrils and throat of the alligator are membrane-like valves. The animal takes a long breath at the surface. Then it closes these valves while it dives to avoid enemies or to pull its prey under the water and hold it there to drown. The valves hold the air in the air tubes and lungs and keep the water out.

FIG. 144. The larva of the Dobson fly lives in the water and gets its oxygen from the water by means of these feathery gills. (P. S. Tice photo)

Plants, of course, have no difficulty in getting oxygen from the air dissolved in water. The leaves of water plants are very thin-skinned, and oxygen can pass directly through them. Some water plants, such as the water-lily, have large leaves that float on the surface of the water. These plants obtain oxygen through pores, or stomata, that are located on the upper surface of the leaf. Land plants have stomata on both sides of the leaf. Not many plants as large as trees or shrubs can grow in the water. But the mangrove, a tree that grows in the shallow water along the muddy coasts in the tropics, is especially adapted for obtaining oxygen for its roots. The roots grow beneath the mud, but they send up branches, or air roots,

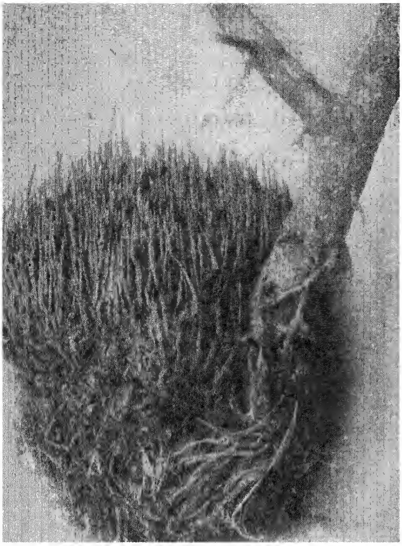


FIG. 145. The woody shoots growing up from the roots of the mangrove are breathing organs. They take in air for the roots growing in the mud where there is little oxygen. (Chicago Museum photo)

above the mud. The air enters the roots through special pores in the bark and goes down to the underground roots through air passages.

Self-Testing Exercises

1. How do simple animals and plants get oxygen?
2. How do fish get oxygen from the water?
3. How do the roots of mangroves get air?

Problems to Solve

1. Find just how the gills of a fish are arranged. Catch a fish or buy one from a fish market. Use scissors to cut the gill cover at top and bottom. Remove it and study the gills.
2. Watch a goldfish in an aquarium. How does it keep fresh water in contact with its gills?
3. Why are gills of little use in dry air?
4. Get some kind of plant that lives under water and examine it carefully to see if you can tell how it gets air.

HOW ARE LIVING THINGS FITTED TO MOVE THROUGH THE WATER? You live in an ocean of air, but you seldom notice the resistance of the air unless the wind is blowing. You can walk or run through it without difficulty. But if you try to run in water, you find that the resistance of the water is so great that it is hard to move with any speed. You can, however, move endways through the water by kicking your feet and using your arms as paddles. A man in water is, however, no match for a fish.

To swim, a fish bends its tail back and forth. The tail is wide and flat so that it forms a good propeller. The body of a fish is shaped so that it slips through the water easily. We say that it is streamlined. Furthermore, the skin of a fish is covered with slime, or mucus, and the scales of most fish point backward. The arrangement of the scales and the mucus that covers them reduce the friction between the body of the fish and the water. Thus the structure of a fish fits it to get around easily in a water habitat.

What other kinds of water animals do you know? No doubt you can name a number of them, including frogs, alligators, turtles, muskrats, beavers, seals, and whales, and you can think of birds, such as penguins and ducks, that are almost as much at home in the water as the other animals. But all of these animals must get oxygen into their bodies by breathing air into lungs; therefore they are really not completely fitted to live in water.

All of these water animals that move rapidly have streamlined bodies, those of the seals and whales being most nearly the shape of a fish's body. These last-named animals also have flat tails and legs, called flippers, that

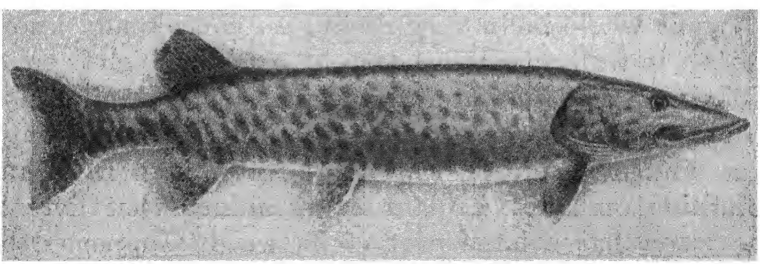


FIG. 146. The northern muskellunge is one of our largest fresh-water fish. Its long, streamlined body makes it also one of the swiftest moving fish. (Chicago Natural History Museum photo)

FIG. 147. These seals may look awkward on land, but their fish-like bodies, flat tails, sleek fur, and flippers help them move very easily in the water. (American Museum photo)

act more like fins than legs. Except for breathing air, they are almost as much at home in the water as the fish. The water animals that spend part of their time walking about on land have quite good legs, but their toes are connected by strips of skin, forming "webbed feet" that are good paddles for swimming.

You can get an idea of another condition found in a water habitat by recalling an experience that almost everyone has had. Did you ever fill a bathtub full of water, lie down in it, and then press your hands against the bottom? If you have done this, you have noticed that you could lift your whole body very easily. As you already know, objects in water are buoyed up by a force which is equal to the weight of the water that they displace (Archimedes' Principle, *Book 2*, pp. 193-197). This lifting effect of water is a kind of condition that is quite different from any condition on land. A plant or an animal that lives in the water has a large part of its weight supported by the water.

Now our question is, How are animals and plants fitted to this condition? A fish will give us a good illustration.

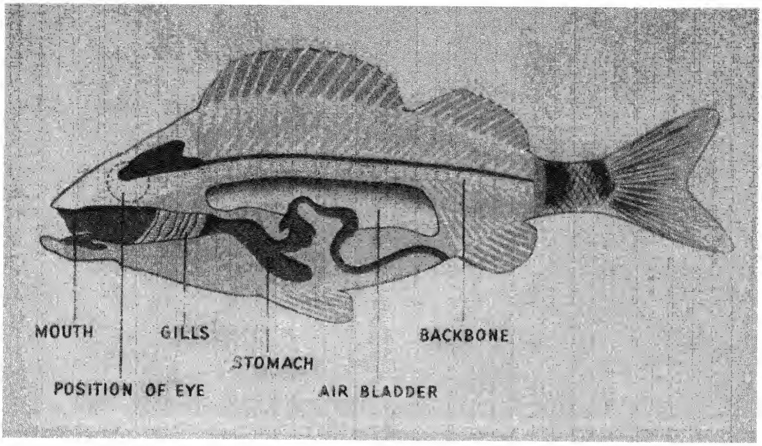


FIG. 148. This diagram shows the location of the air bladder in the perch. Notice that it takes up a considerable amount of space.

As you watch most fish in the water, you see that they seem to float at any depth without effort. To do this, their bodies must have the same average weight (density) as the water. But the muscles and bones that make up the larger part of a fish's body are heavier (more dense) than water; that is, a cubic inch or foot of muscle or bone weighs more than a cubic inch or foot of water. Therefore the fish would sink to the bottom if it did not have some structure to help it float.

Most of the common fish have such a structure. It is an air bladder inside their bodies just below the backbone. This bladder works on the same principle as the water wings that children use before they learn to swim. This bladder is just the right size to have the water support the fish. In this way most fish can without effort remain at any reasonable depth and rest motionless in the water. Fish that have no air bladder either rest on the bottom most of the time or keep swimming to avoid sinking.

You can see that the air bladder is a very good adaptation to water life. The lungs of air-breathing water animals act much like the air bladders of fishes, so that their bodies are the same density as the water or just a

little lighter. Frogs, crocodiles, and hippopotamuses can just float in the water. The eyes and nostrils of these animals project. Thus they can see and breathe above the surface while floating almost hidden in the water.

There are also other ways in which an animal may be adapted to take advantage of the lifting effect of the water. You have probably heard that fat people can float more easily than thin people. If you put a lump of butter in water, you can see why. Butter is largely fat, and it can float. An animal that has a great deal of fat or oil stored in its body thus weighs less than the water it displaces. Most small floating crustaceans contain little bubbles of oil scattered through their bodies. These liquid bubbles, being lighter than water, enable the animal to float.

The lifting effect of water also makes possible animals that would not otherwise exist. For example, what do you suppose would happen to a jellyfish (page 97) if it were brought out on land? In the water jellyfish are bell-shaped creatures, sometimes of great size. But ninety per cent of a jellyfish's body is water. It displaces its own weight in water; therefore it floats. On land it would collapse into a shapeless mass. It has no bones or hard parts to support its body. It does not need these in water because it does not have to support its weight. The largest animals in exist-

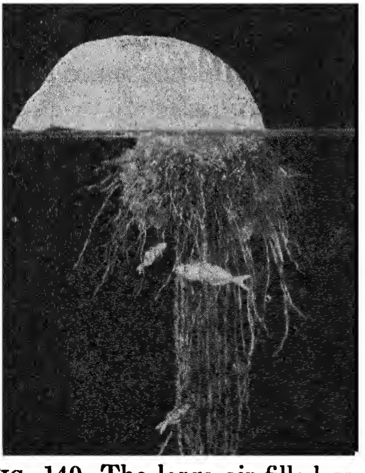


FIG. 149. The large air-filled sac acts as a float for this animal, known as the Portuguese man-of-war. (Amer. Mus. photo)

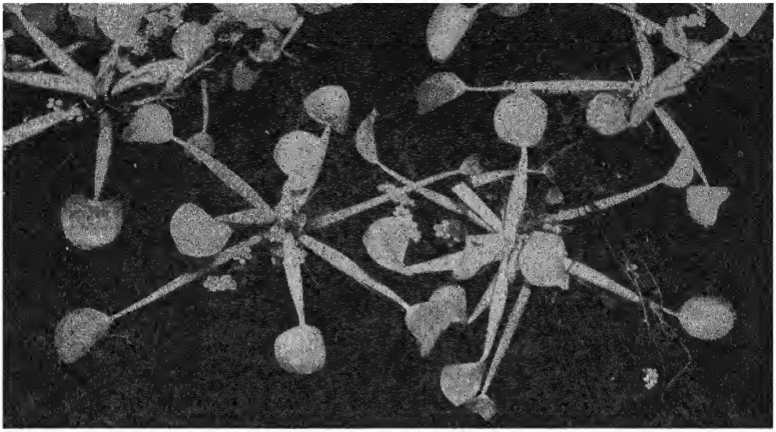


Fig. 150. The water hyacinth is not attached to soil in any way, but floats about on the surface of the water. The plant is buoyed up by the bladder-like enlargements of the leaf-stems, or *petioles*.

ence today are whales. They may reach a length of ninety-five feet and a weight of nearly 300,000 pounds. Such an animal could not exist on land, because it could not have bones large enough or strong enough to support such a tremendous weight.

Plants, too, have adaptations that fit them for life in the water. Air spaces in leaves and stems help them to float upward toward the stronger light near or on the surface. Many water plants even have bladders in their stems and leaves to help them float (Figure 150). You can see that stiff stems and branches are not needed to support water plants; they are supported by the water. In another way the flexible blades and stems of water plants help them to stay alive: The plants can bend and sway easily as the water moves in currents and waves. If the stems and the leaves were stiff and unyielding, as they so often are in land plants, the plants would be easily broken and washed away.

From what you have just read, you can easily see that animals and plants living in water do not need a strong framework to support their weight. You can also see one reason why they could not stay alive on land.

Self-Testing Exercises

1. Name two ways in which many water animals are fitted to move swiftly through water. Give several examples of each.
2. Why can you move through the water by kicking your feet and moving your arms?
3. Why will a fish with an air bladder float, while a fish without an air bladder will sink?
4. Whales have a very thick layer of fat, or *blubber*, under their skin. How may this help adapt them to live in water?
5. What structures do water plants have that are not necessary for land plants?
6. Why are stiff stems needed by land plants but not by water plants?

Problems to Solve

1. Why can you float in water more easily if you first take a deep breath?
2. Find out how ducks are adapted to floating on water.
3. If you can visit a pond or stream, find different kinds of water plants and discover what structures enable them to float.
4. For what purpose does a goldfish use its tail? Its fins?
5. Find out how beavers, crocodiles, frogs, crayfish, water-bugs, hippopotamuses, and turtles move through the water.

HOW ARE LIVING THINGS FITTED TO GET FOOD FROM THE WATER? An animal that had no way of moving about on land would soon starve, because there is little, if any, food in the air around us. Almost every land animal has to move around in search of food. But conditions are quite different in the water. Microscopic plants and animals by the millions are floating in the water. It is not surprising, therefore, to find water animals that do not move about much; they remain in the same place or move very slowly along the bottom. Several invertebrate animals are in this group: hydras, oysters, clams, and sponges.

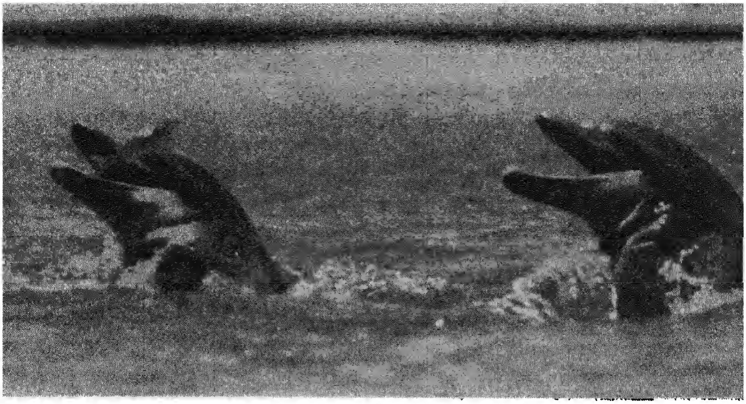


FIG. 151. The porpoise's mouth is well adapted to capturing fish, and its sleek, streamlined body enables it to move swiftly through water. Porpoises belong in the same order with whales. (J. C. Harris photo)

Hydras, with their relatives the sea-anemones, capture food, as you know, by shooting poison darts into animals that strike their tentacles. Clams, sponges, and other animals make currents in the water by means of cilia. These currents bring food particles and oxygen into their bodies and carry away carbon dioxide and other wastes. A fish can eat as it swims. The water coming in through its mouth brings in its food. As the water flows out through the gills, it passes a row of projections like the teeth of a comb. These structures are called *gill rakers*. You can see them in Figure 143. They let the water pass between the gills, but guide the food into the esophagus.

Plants, of course, have no difficulty in getting minerals from the water. The outer layers of the roots of water plants are not thick like those of land plants. Water and minerals can be absorbed by the entire length of the root. Some water plants do not have roots at all; they absorb materials directly through their green parts.

Since plants need light for the manufacture of their food, adaptations that make it easier to obtain light are important in the life of water plants. Air spaces in leaves and stems help them to float upward toward the stronger

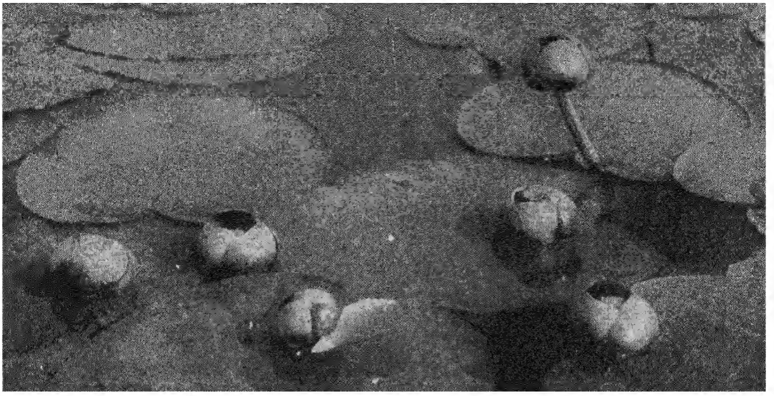


FIG. 152. The broad, flat leaves of the water-lily, floating on the surface, are fully exposed to the sunlight. (L. W. Brownell photo)

light near the surface. Leaves of plants that grow below the surface of the water, where the light is dim, are very finely divided. Because of this, many more cells of the leaf are exposed to whatever light there is. The mermaid weed is a plant that shows this kind of adaptation in an interesting way. On the same plant the leaves that have grown under the water are divided into many small parts, while the leaves that grow above the water are broad and flat.

Self-Testing Exercises

1. In what ways are conditions for food-getting different in water from what they are in air?
2. How are water plants fitted for making food?
3. How do different animals capture food floating in the water? Describe several ways.

HOW ARE ANIMALS FITTED TO THE TEMPERATURE CONDITIONS IN WATER? For an animal living in water, the weather must be somewhat monotonous. Of course, it is always wet, and temperature changes take place much more slowly than on land. The water does not cool off at night nor warm up much in the daytime. When summer comes, the water becomes warm very slowly, and it never gets as warm as the air on a hot day. When winter returns, the water also cools slowly, and it does not go

FIG. 153. This whale was protected from the cold by the thick layer of blubber that these men are cutting off in great strips for the purpose of getting the oil from it. (Paul's Photos)

below freezing temperature. Some ice may form on the surface, but beneath the ice the temperature of the water will not fall below freezing. This is quite different from the temperatures on land where it may be 40° below zero in the winter and as hot as 120° on a summer day. Animals and plants living in water do not have to be protected from blazing sun and biting cold.

Some water animals, like the whale and seal, are warm-blooded. They are insulated from the cool water by layers of fat, or blubber. Fishes, amphibians, arthropods, clams, and many other animals are, as you know, cold-blooded animals. Their bodies stay at about the same temperature as the water. In winter, as the temperature goes down, these animals become less active, and at the freezing temperature they stop moving. They stay this way until the water gets warmer. As the water gets warmer, they become more and more active. Many of the invertebrate animals can remain in a temperature below zero for a considerable length of time; then, when they are gradually warmed, they "come to life" again.

Self-Testing Exercises

1. How does the temperature of the water differ from that of the air?
2. How are cold-blooded animals adapted to living in the water?
3. How do warm-blooded water animals keep from losing their body heat?

HOW ARE DEEP-SEA ANIMALS FITTED TO THEIR SURROUNDINGS? Near the surface of water there is little pressure, but, as you learned in *Book 2*, for each foot of increase in depth the pressure increases almost one-half pound. At a depth of 100 feet the pressure is more than forty-three pounds per square inch, and a mile down in the ocean it is more than 2300 pounds per square inch. Animals have been brought to the surface from a depth of 23,000 feet. At this depth the pressure is about 10,000 pounds per square inch.

Curiously enough, the animals do not feel this pressure any more than you feel the atmospheric pressure of fifteen pounds per square inch. The pressure on the outside is balanced by the pressure of the blood and of the fluids in the cells. You have probably heard that deep-sea fish explode when brought to the surface. This is true for those fish that have gas bladders, particularly if they are brought to the surface very rapidly. Many of the deep-sea fish do not have gas bladders and therefore may be brought to the surface without exploding. However, they are usually dead, and come up swollen and with their stomachs forced out of their mouths.

Food-getting at great depths is quite a different problem from food-getting near the surface of the sea. Light is quickly absorbed as it passes through the water, and at a depth of 300 feet there is total darkness. This means, of

course, that green plants cannot live at this depth. As a matter of fact, green plants are not found at a depth of more than 150 feet. Thus there are no plants to serve as food for deep-sea animals. Practically the only food they get is obtained from the dead bodies of plants and animals that sink in the water. Of course, they can prey on other animals, but the population of the deep sea is not large; so this source of supply is very limited.

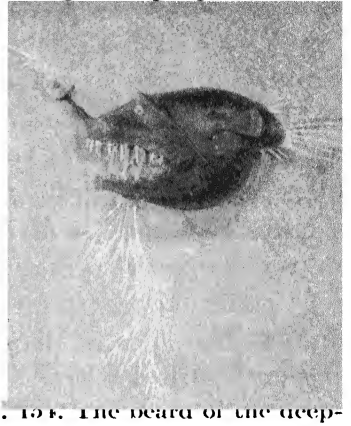


FIG. 154. The beard of the deep-sea angler fish is probably luminous. (Amer. Museum photo)

Naturally, you would not expect deep-sea fish to be very large, because of the small amount of food there is for them to eat. Most of these fish, even though they look so ferocious in pictures, are not over a foot in length. Deep-sea fish differ greatly from those of upper waters in the size of their jaws. Their jaws are out of proportion in size to the rest of their body. These jaws enable them to grasp the large bodies that sink slowly from above.

The most curious adaptations of deep-sea animals are *phosphorescent organs*. These organs give out cold light. They shine like phosphorus, or the glow of fireflies. Some of these organs are like the headlights on an automobile, and they help the animal find its way about and discover food. Other phosphorescent organs are in strange patterns over the body of the animal. These patterns apparently help the animal to identify other animals of its own kind and also its enemies. One kind of deep-sea fish has a kind

of fishing rod on its head. On the end of the rod is a luminous organ. The rod is hinged in the middle and is apparently thrown forward when its prey is attracted and then moved back, luring its prey close enough for its capture.

You have probably heard of the cuttlefish that can squirt out a dark, inky liquid from its body. This liquid serves as a "smoke screen" to help the cuttlefish escape. Of course, a black liquid would be of no value far down in the sea where there is no light. Believe it or not, there is a deep-sea cuttlefish that squirts out a luminous cloud that baffles its pursuers and enables it to escape.

Since there is little or no light far down in the water, you might expect to find that deep-sea animals have different kinds of eyes from those possessed by shallow-water animals. The eyes of deep-sea animals are enormous, as compared with the size of the animal. In some animals the eyes occupy two-thirds of the whole head. The bigger the eye, the greater the amount of light that can be gathered by it. The lens of the eye, too, is constructed in such a way that the light is concentrated upon a very small portion of the sensitive back part, or retina. While most of the deep-sea fish have large eyes, in some kinds the eyes have degenerated; that is, they have become less and less sensitive to light, or not at all sensitive to it. In some of the

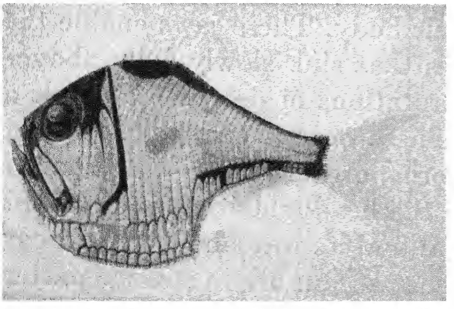


FIG. 155. A deep-sea fish with its strangely large mouth and its large eyes. (Chicago Natural History Museum photo)

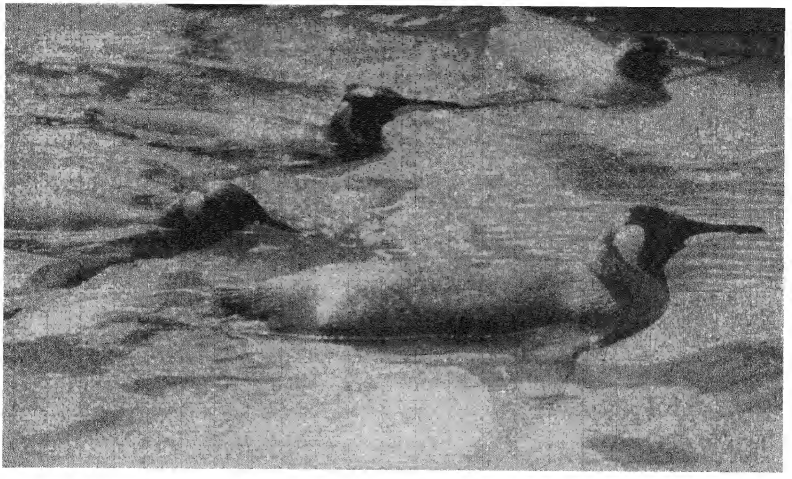


FIG. 156. Although we usually see penguins strutting about on land, they are excellently adapted for swimming, with their paddle-like wings, webbed feet, and long bodies. (H. Armstrong Roberts photo)

great caves of our country, where there are ponds and streams, there are actually blind fish. On these fish you can find only a spot where the eye used to be. In most of these animals there has been an increase in the keenness of other senses, such as touch.

Self-Testing Exercises

1. Name several ways in which deep-sea fish are adapted to live at great depths.
2. Why do deep-sea fish not feel the pressure of the water?

Problem to Solve

Find out how men work under water. What precautions have to be taken to fit them to the increased pressure?

WHAT ARE THE CONDITIONS OF A WATER HABITAT? As you think back over what you have just studied, you can see what the conditions in a water habitat are. The living thing is surrounded by water. This water exerts a lifting effect upon the living thing and helps to support it. Furthermore, water offers resistance to the

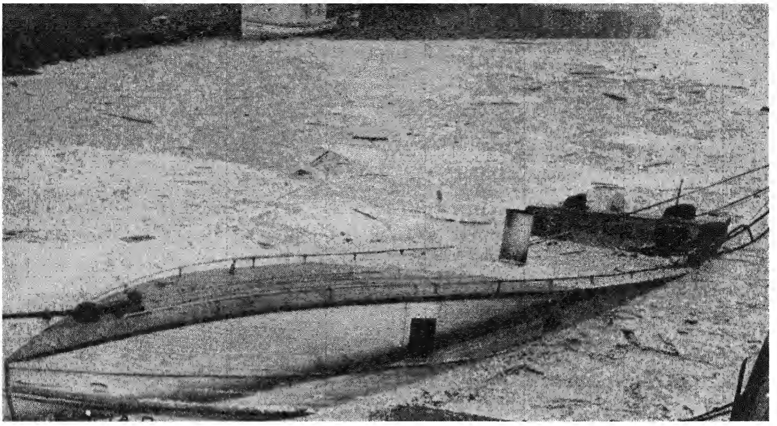


FIG. 157. The surface of the water is covered with millions of minnows that could no longer live because the oxygen supply in the water became insufficient. For certain reasons the water stopped flowing at this particular spot. Soon the minnows used up all the oxygen, and there was no fresh supply of water to bring in more oxygen. (Chicago Tribune photo)

passage of objects through it. This resistance has two effects: (1) It enables the living thing to pass through the water by moving some part of its body, such as its tail or fins or legs. The moving part really pushes against the water, and in this way the animal moves itself. (2) It hinders the passage of living things through the water and makes necessary a streamlined body if the living thing is to move at all swiftly and easily.

The water also contains oxygen dissolved in it. Since there is no danger of drying in a water habitat, and since there are no great changes in temperature, living things do not need thick skins for protection. Many water animals and plants can absorb oxygen directly through the skin; others have gills that take oxygen from the water that passes over them. Food, too, is easy to get in water, because the water contains millions of tiny plants and animals.

You have been reading only about the conditions that

we usually find in water habitats. There are many different kinds of water habitats, each of which has a different set of conditions. All of the conditions that you have read about are present, but they differ greatly in some respects. You can easily see that the conditions in a shallow pond, a deep fresh-water lake, the cold springs under the surface of the ground, the running water of a brook or river, the shallow water of the seas, and the deep water of the oceans are very different.

You will find that there are different kinds of plants and animals in each of these different habitats. Each kind of living thing is so constructed that it can live in habitats that have certain conditions. Most living things cannot migrate to other habitats if the conditions become unfavorable in the habitat where they are living. If the conditions in any habitat change a great deal, usually most of the living inhabitants die, as shown in Figure 157.

Self-Testing Exercise

Make a list of the conditions in a water habitat that are different from those in air.

Problems to Solve

1. Make a list of all of the ways in which a fish is adapted to live in a water habitat.

2. Make a list of all the different kinds of body structures that you can find to fit animals for support and locomotion in the water.

3. How are the following animals adapted to water habitats: squid, octopus, hippopotamus, wading birds? Choose one or two of these animals and learn all that you can about them from reference books. Then list the ways in which they are fitted for the kind of life they lead. Do not depend on the books to tell you all the adaptations. Think of them yourself.

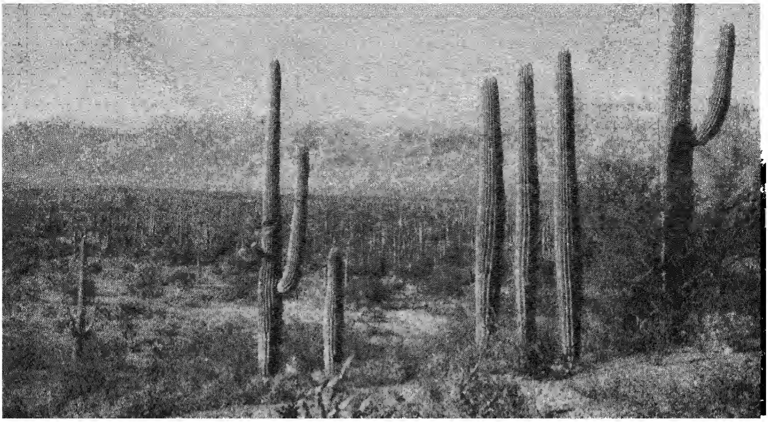


FIG. 158. The trees in this "forest" near Tucson, Arizona, are the strange giant cacti that are so well adapted for life in desert regions where there is little moisture. (K. C. Hamner photo)

Problem 2:
HOW ARE ANIMALS AND PLANTS FITTED TO LIVE ON LAND?

WHAT ARE THE CONDITIONS OF A LAND HABITAT? As you think back over what you have studied, you can see that the conditions of a land habitat are vastly different from the conditions in a water habitat. On land the living thing is surrounded by air. Unlike water, the air has almost no lifting effect; therefore land plants and animals need a framework to support the weight of the body. Also, it is easy to move through air. In studying adaptations to land life, you will learn how living things support themselves on land and how they move on land or in air.

You know that all living things must have water. On land the drying effect of the air and the heat from the sun have made necessary the development of structures to prevent the liquid part of the body from evaporating. Furthermore, land animals and plants must have structures to get air into the body, because air has in it the oxygen that living things need. The temperature of the air varies so greatly that land animals have developed structures to protect themselves.

FIG. 159. This speeding herd of pronghorn antelopes was photographed from an airplane directly overhead. The antelope is one of the swiftest moving of land animals. (Charles J. Belden photo)

Like water, the land has a great variety of habitats, and the conditions are different in each of them. The conditions in a desert, in a tropical forest, on the plains, in the far north, and on a mountain top are greatly different. Each different kind of land habitat has its own living inhabitants that are adapted to live in the conditions that are found there.

HOW ARE LIVING THINGS FITTED TO MOVE THEIR BODIES FROM PLACE TO PLACE? Being a land animal yourself, you already know many things about the conditions of a land habitat. You yourself are adapted to live in such a habitat. If you have never thought about how you are fitted to live on land, you might look yourself over and see how the various structures that you possess are adapted to the conditions of land life. As you read through the sub-problem, you can find other adaptations.

An animal living on land has the solid earth beneath it and the air around it. The air, being very light, has practically no lifting effect. This means, therefore, that an animal must be constructed so that it can support its own weight. A few animals, such as the earthworm and snake,

lie flat along the ground, but most of the animals you know have legs that lift their bodies off the ground.

When the body of an animal is lifted off the ground by legs, strong bones and ligaments are needed to tie those bones together. Strong muscles are also necessary to hold the parts of the body in a proper position. Insects, of course, have no bones, but they do have hard parts on the outside of their bodies to which the muscles are attached. Their weight, however, is so small that these hard parts are strong enough to support their bodies. Any animal whose body is supported by legs must have a more or less rigid framework.

Unlike water, the air around us offers little resistance to our bodies as we push through it. This is quite an advantage to animals, because it helps them to move at a much higher speed than water animals. This small resistance of the air, however, makes necessary a different type of locomotion from that used by water animals. You can throw your hands around like a windmill and kick your feet, but still you cannot move. Fortunately, the land beneath your feet is solid. If you push against it, it will not move out of the way as water and air do.

The best kind of structure for moving on a solid surface such as land is two or more legs. You push one foot ahead; then you rest your weight on it, and draw up the other foot and place it ahead. On solid land or on sidewalks and streets you do not slip; thus you move your body forward. Other animals with legs move somewhat in the same manner. Because of the friction between the animal's feet and the ground, the animal can push or pull its body along the ground.

Some animals, such as birds and insects, can fly through the air. They are really heavier-than-air flying

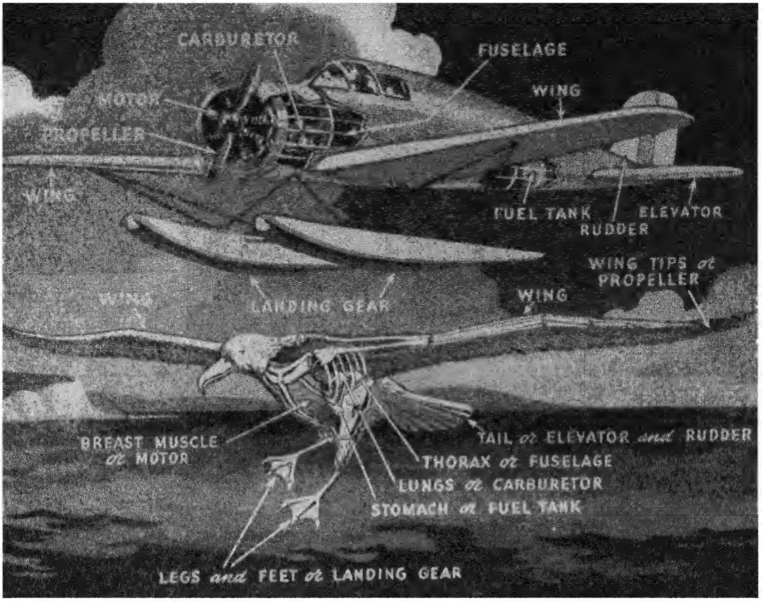


FIG. 160. A comparison of a water bird with a seaplane. The Indians in South America call an airplane a "Thunderbird." Do you think this is a good name for it?

machines. But their bodies are adapted for this purpose. Actually the weight of a bird is rather small, considering its size. Perhaps you did not know that the long bones of the bird are hollow and that there are air spaces in its body. This cuts down the weight of the bird. When a bird is flying, its wings beat the air and serve the same purpose as the propeller of an airplane. When a bird is soaring, its wings can be placed at a correct angle to the air currents. Short feathers on the rest of the body keep it streamlined so that it will not offer much resistance to the air.

Plants, too, need structures to support their weight on land. When water plants are brought out on land, they collapse because they have no stiffening structures in their stems. In land plants there are long fibrous cells contained in the vascular bundles. These cells dovetail with each other and give strength to the stem. If you have ever tried to break a fairly large twig from a tree, you have

FIG. 161. Rope and cables are made from fibers taken from the hemp and jute plants. If you try to pull a tiny strand of rope apart, you can see how strong these fibers are. (Ewing Galloway photo)

seen how difficult it is to twist it from the tree. The fibers are so strong that a young tree can be bent almost to the ground by the force of the wind without breaking off.

Self-Testing Exercises

1. How is moving on land different from moving in water?
2. How do land animals support their weight?
3. How is the weight of land plants supported?
4. How are birds adapted for flying?

Problems to Solve

1. Find out how "flying" squirrels and "flying" fishes are fitted to move through the air.

2. Why is it more difficult to walk on ice than on soil?

3. Find out how the feet of animals are adapted for different kinds of land conditions. Consider the camel, the elephant, the deer, and the lion.

4. Think of all land animals as either walking, crawling, climbing, or flying animals. Make a list of animals in each group, and study the structures that help each animal to move in the way it does. For example, why can cats climb trees, while dogs cannot do so?

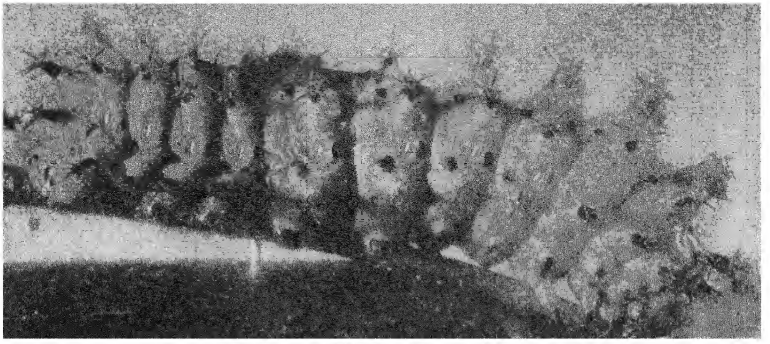


FIG. 162. The white dots along the side of the Cecropia moth larva are openings through which air enters. (Geo. T. Hillman photo)

HOW DO PLANTS AND ANIMALS GET OXYGEN FROM THE AIR? Living in an ocean of air presents still another problem. Living things must be able to get oxygen out of the air. Many of the animals living in water can get the dissolved oxygen in water by absorbing it through the thin walls of their bodies. But if water and oxygen can pass through the body from the outside to the inside, they can also pass in the other direction. A skin that allows water and oxygen to soak through it will not protect the animal from the drying effect of the air. The structures of a land animal must be such that it can get water and oxygen from its surroundings and that it can keep the water that it needs.

All reptiles, birds, mammals, and many adult amphibians breathe by means of lungs. Air is taken into the lungs, which are surrounded by tiny blood vessels. Oxygen passes through the thin walls of the lungs and blood vessels to the blood. Carbon dioxide passes from the blood to air in the lungs and is then expired from the body. Insects have a different method of getting air. A system of air tubes runs through their bodies. These air tubes have tiny openings on the skin. The air is pumped in and out of these openings by the expansion and contraction of the body. Land animals thus need structures to enable them to get air into their bodies, where it can come in contact

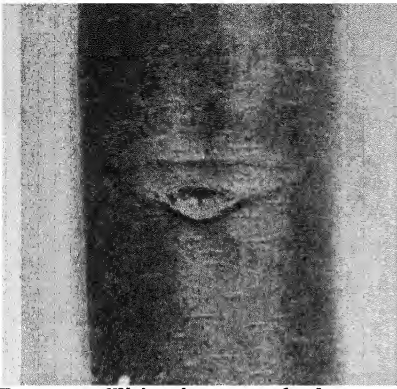


Fig. 163. This photograph shows lenticels in the bark of the basswood. (G. D. Fuller photo)

Fig. 164. The so-called "horned toad" is a desert lizard. It has a thick skin. (Brownell photo)

with the blood vessels that carry the needed oxygen to all parts of the animal's body.

Plants, of course, have no lungs or other organs to pump air in and out of their bodies. The molecules of oxygen diffuse in through the stomata, which are tiny pores in the leaves. The bark of trees and shrubs also has pores that let oxygen diffuse through the thick corky layers that protect the stem. These pores, called *lenticels*, are important to plants because they make it possible for the living cells beneath the cork to get oxygen.

How are living things kept from drying out in a land habitat? If you leave a drop of water on the table for awhile, you know what will happen. It will evaporate. A wet cloth will also become dry by the evaporation of water. Exactly the same thing would happen to the liquid part of your body if there were no means of preventing it. A large per cent of the bodies of all animals is water. There is water in the cells of animals, water makes up the liquid part of the blood, and water is a necessary part of all the digestive juices. If an animal is to keep on living, it must have some way of keeping the liquid part of its body from evaporating. Of course, this is easy for water animals. They are surrounded by water at all times.

When we study the structure of land animals, we find that they have thick skins. These skins are water-tight. Not only do most of the animals that you know have thick skins, but their bodies are covered with fur or hair. This fur or hair still further protects the body of the animal from drying up.

One of the animals most remarkably adapted to its habitat is the camel. One species of the camel lives in a region of drought, sand and rock, and little vegetation. It must withstand the burning heat of the sun. In a place such as this it may be a long time between drinks. But the camel is ready for such an emergency. Its stomach is supplied with water-storing sacs. Perhaps you have heard that a camel can go five days without a drink. Now you see how this is possible.

Food, too, is scarce in the desert, but the camel is also provided with a pantry. Food is stored in its hump. When the camel is well fed, this hump is large, but the hump gradually shrinks during long hard labor with little food. These two adaptations, together with its shaggy coat, its padded feet, and its long overhanging lids and eyelashes which protect its eyes from the powerful rays of the sun, fit this animal to live very well in a habitat where few animals can live.

One land animal that you have studied, the earthworm, does have a thin skin. It can also breathe through this skin. The body of an earthworm, however, is covered by a slimy sort of liquid that keeps the skin moist. The earthworm stays in the ground during the daytime, so that the sun never gets a chance to shine on its body. The drier it is, the deeper into the ground the earthworm digs. At night, particularly when there is a heavy dew, it comes up to feed. While the earthworm is not adapted to living a

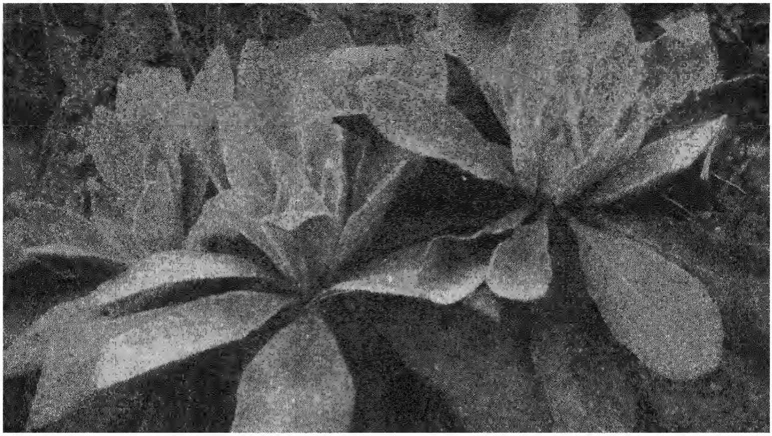


FIG. 165. The leaves of the mullein are covered with hairs that probably reduce the circulation of air close to the surface of the plant; therefore evaporation cannot go on so rapidly. (Brownell photo)

life above the soil, it is fitted to live beneath the ground. All animals, however, that live on the surface of the ground, where their bodies are exposed to the rays of the sun, must have a thick skin or other structures to keep their bodies from losing their water content.

Protozoans and other microscopic animals usually form a thick outer coat around their bodies when they begin to lose water. Then they pass into an inactive state. When water is again available, they soak it up and start an active life again.

Plants are fitted in many ways to prevent the loss of too much water. Water is constantly being evaporated into the air from the leaves through stomata. The guard cells on either side of the stomata regulate the opening and closing of the pores, and in many plants this regulation helps the leaves keep their moisture. As a further protection, most of the stomata are located on the underside of the leaf, where they are partly protected from the hot rays of the sun. Many leaves have a layer of special material on their epidermis. This acts as waterproofing for the leaf.

Plants in the desert, where the air is hot and dry, show the most marvelous structures to prevent the loss of moisture. The cactus is a good example. The leaves of the cactus are very small (the thorns or spines are really leaves), or else there are none at all. The work of photosynthesis is carried on by the swollen stems of the plant. The amount of surface exposed to the air is very small as compared with the volume of the stem. During periods of rain the thick fleshy stems of cactus can store water for the dry times ahead.

Self-Testing Exercises

1. Why must the bodies of land animals be protected from drying?
2. How are the bodies of animals protected from drying?
3. Why do earthworms die if exposed to the rays of the sun for a time?
4. How is the camel adapted to live in the desert?
5. How are plants protected from drying?

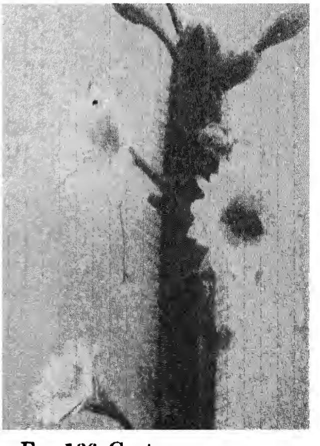


FIG. 166. Cactus. Spines and fleshy stem. (Chicago Museum photo)

Problems to Solve

1. Why is a frog not entirely adapted to living in air?
2. Why does a fish soon die if left out of water? (There may be several reasons.)
3. Why is it advantageous for more stomata to be located on the underside of leaves than on the upper side?
4. Examine plants grown in a rock garden. How do they differ from the plants we ordinarily grow in gardens?
5. Work out a good explanation of how hairs on a plant cause slower evaporation. Find specimens of hairy plants.

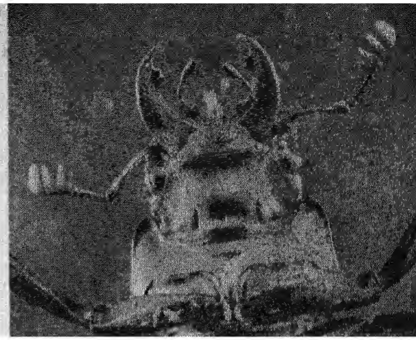


FIG. 167. A snarling wild-cat shows his teeth.

FIG. 168. The biting mouth-parts of the stag beetle (P. S. Tice photo)

HOW ARE LIVING THINGS FITTED TO GET FOOD IN A LAND HABITAT? Unlike the water, air has little, if any, food floating in it that can be taken by the animal as the air moves by its body. Consequently, we do not find land animals that are fixed to a certain spot, like a sponge. Land animals must move around from place to place to get their food. They can do this because they have structures for moving themselves. Like water animals, land animals have parts that enable them to seize their food. Jaws, claws, beaks, teeth, and rasping tongues are some of the structures that help animals to get food.

Plants living on land must be quite different from plants living in water. You already know some of these differences. Land plants must be able to get carbon dioxide from the air. The leaves of plants are arranged on a tree in such a way that they may get the greatest amount of light energy from the sun. Land plants need well-developed root systems. Trees, for example, must send their roots many feet in all directions to get the necessary water and minerals from the soil. Many roots give off acids that can dissolve the minerals in the soil so that the plant can use them. The stems, too, need tissues to transport water and minerals from the roots to the leaves, and they need other tissues to transport the manufactured food to the cells of the plant.

Self-Testing Exercises

1. Why would an animal that is unable to move have a difficult time living on land?
2. In what ways is the structure of a land plant different from that of a water plant?

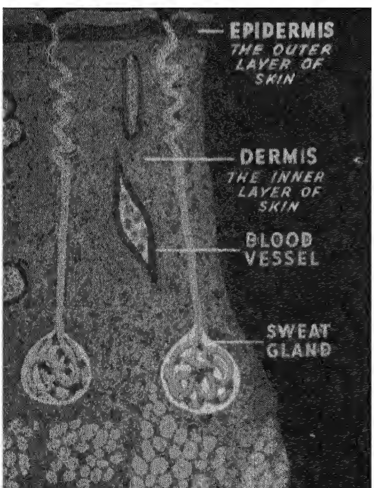
HOW ARE LIVING THINGS FITTED TO THE TEMPERATURES OF THEIR SURROUNDINGS? In the middle and northern parts of the United States, as well as in other parts of the world, there are great changes in temperature during the year. The temperature at one place may fall as low as 40° below zero in the winter and rise as high as 120° in the sun during the summer months. Many plants, such as trees and bushes, and many animals, such as coyotes, bears, deer, wolves, opossums, raccoons, and woodchucks, can live all the year round in these regions. To do this, they must be able to adapt themselves to this great range of temperature.

You already know one way in which animals are adapted to live under different conditions of temperature. All of the animals mentioned above have a temperature-regulator inside their bodies. You yourself have one. Your temperature stays always at about 98.6° F. unless you are sick. Your body, as you know, is warmed by the oxidation of food in the cells. In cold weather oxidation is speeded up to keep the inside of your body warm.

FIG. 169. The African aardvark gets ants from the hard ant-hills with his strong claws, long snout, and sticky tongue. (Field Museum photo)

In warm weather oxidation becomes much slower. The blood is a kind of heat-distributing system like the pipes of a hot-air heating system. When the temperature is cold, the blood vessels in your skin contract, and the blood is sent to the inner parts of your body. In this way little heat is lost from your body. When the temperature is warm, your body must lose heat. The blood vessels in the inner parts of your body contract, and those in the skin expand. More blood thus flows through the skin and loses heat by radiation and conduction.

When it is very hot, or when you exercise vigorously, your body pours perspiration on the skin. This perspiration, which is largely water, evaporates. When water evaporates, heat is required. The heat comes from your body, and thus your body is cooled. Of course, we help our bodies to remain at the proper temperature by wearing the correct amount and kind of clothes. All warm-blooded animals have ways of keeping the temperature of the body the same at all times. Perhaps you have observed a dog when it is hot. It opens its mouth and "pants," with its tongue hanging out. The rapid movement of the air past the tongue and the lining of the mouth and the throat carries away much of the heat as the liquid on these surfaces evaporates.



the human skin, showing sweat glands

Animals living in the far north must, of course, be able to withstand very low temperatures. These animals, such as the Arctic fox, the Arctic hare, and the lemming, have

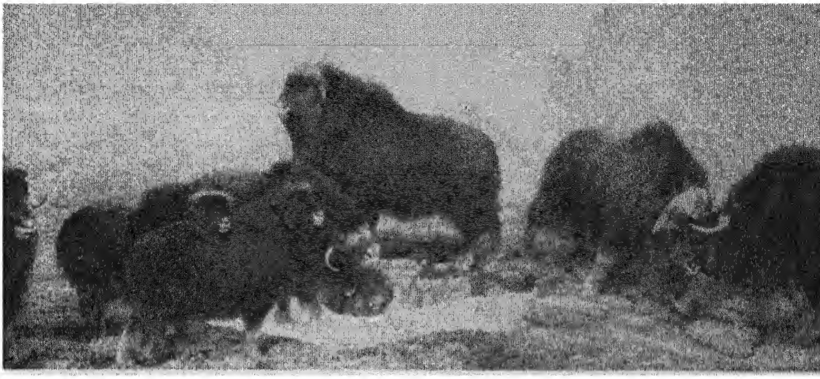


FIG. 171. The outer hairs of the musk-ox may be as long as two feet; thus they provide a thick cover to keep the inner coat of wool quite dry. (Field Museum photo)

a wooly undercoat. Outside this there is soft, silky outer hair. Animals living in cold climates also have a layer of fat beneath their skin. Fat is a good heat insulator and helps the animals keep their bodies warm. It also serves another purpose. During the long winter months, when food is scarce, the animals can draw on this reserve of fat for food.

Other animals, such as woodchucks, raccoons, bats, and sometimes bears, seek a sheltered spot and pass into an inactive state, known as *hibernation*. While they are hibernating, the temperature of their bodies drops several degrees, and the rate of breathing and of the heart-beat slows down. Only very little energy is required to keep the animal alive. This energy is supplied by the fat stored in the body. Frogs, many insects, and snakes also hibernate during the winter.

Plants, too, have structures that enable them to endure a great range in temperature. The structures that help plants to keep water also help to protect them from changes in temperature. During the winter months, when the ground is frozen, trees cannot get water from the soil. They would soon lose their water content by evaporation from their leaves if it were not for the fall of the leaves

FIG. 172. Some animals meet the problem of the change in temperature during the winter by *migrating*. Every year many birds fly south at the beginning of cold weather and fly back at the beginning of spring. You have probably heard people say, "Well, spring is coming, the ducks are flying north." (Ewing Galloway photo)

during the autumn months. The evergreen trees that keep their leaves have leaves which are very narrow and thick. This size and shape prevent the loss of water during the winter months. Also, the leaves are coated with materials that are waterproof.

Self-Testing Exercises

1. How does your body (*a*) keep itself warm in cool weather and (*b*) cool in hot weather?
2. How are arctic animals protected from the cold?
3. What are some of the ways in which plants are protected from hot and cold weather?
4. Why is migration a valuable adaptation of animals?
5. Explain why hibernation is called an adaptation.
6. Compare the conditions present in a water habitat and in a land habitat.
7. Explain why an animal adapted wholly to living in water cannot live on land.
8. Explain why an animal adapted wholly to living on land cannot live under water.

Problems to Solve

1. Make a list of the kinds of animals that hibernate.

2. Make a list of the kinds of animals that migrate in spring and autumn.

3. Watch some sparrows on a very cold day. What do they do to keep warm?

4. Find out what happens to the coats of horses that are left out-of-doors during the winter.

5. Learn from reference books the meaning of the word *aestivation*. Show how this is an adaptation.

6. How is a dandelion fitted for life in its habitat? Consider all the dangers that dandelions meet when growing in a well-cultivated lawn where man is trying to get rid of them. What adaptations help them to continue growing there in spite of man's efforts to get rid of them? Talk with people who have lawns to learn what they know about dandelions.

7. Find out the kinds of adaptations that nocturnal animals have; for example, consider the cat and the owl.

8. Why are toads not entirely fitted to life on land? If you do not know the life history of toads, read about it in reference books. Or remember what you know about the reproduction of frogs; the reproduction of toads is about the same as that of frogs.

9. What adaptations are shown by each of the following? Choose one or two examples. Learn about them by observation, by reading, or by talking to persons who know. Then make a report to your class.

Grasshoppers	*Bats*	*Beaks of birds*
Bees (especially the legs)	*Flowers (and insects)*	*Teeth of mammals*
		Moles

10. Collect some water plants and some land plants. Compare them as to their likenesses and differences.

11. Find out how the feet of moles, squirrels, raccoons, gophers, and birds adapt them to the kinds of habitats in which they live.

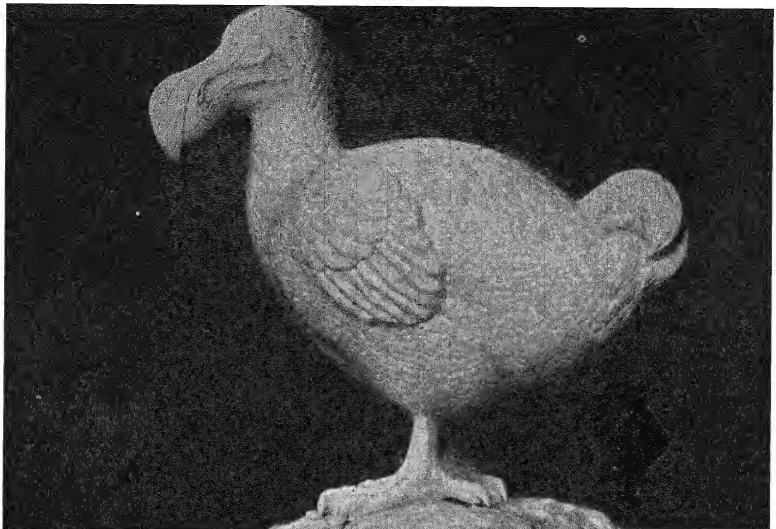


FIG. 173. A model of the dodo, a bird that could not survive because it was unable to protect itself. (Chicago Museum photo)

Problem 3:

HOW DO THE STRUCTURES OF LIVING THINGS PROTECT THEM FROM THEIR ENEMIES?

HOW ARE ANIMALS PROTECTED? When the Dutch first colonized the island of Mauritius in 1644, they found there a bird which they called the dodo (meaning *sluggard*). It was a stout, clumsy bird about as large as a swan. It had short legs and could not run fast. It had small wings and could not fly. As it had no way of defending itself, it was easily captured. It was also excellent eating. The sailors and colonists killed dodos by the thousands. Pigs, dogs, and monkeys, brought by the early explorers, joined in the destruction, and within thirty years the dodo was exterminated. Today there are no dodos anywhere in the world.

Many stories can be told about species of animals that have become extinct because they lacked means of defense against their enemies. Those that have survived have some means of protection, or they have developed habits that help them to escape from their enemies.

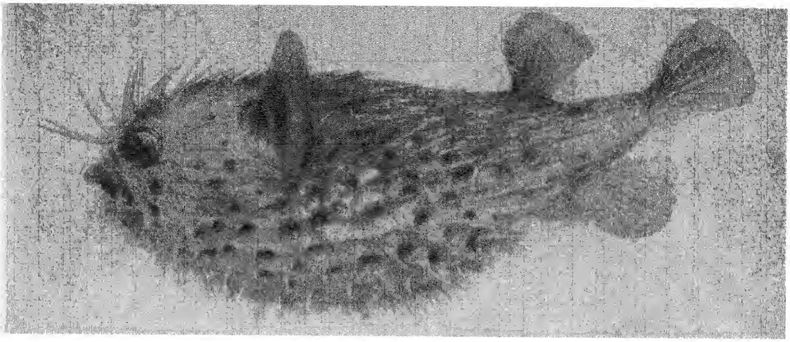


FIG. 174. The porcupine fish would be a prickly mouthful for any larger fish that tried to eat it. (Chicago Museum photo)

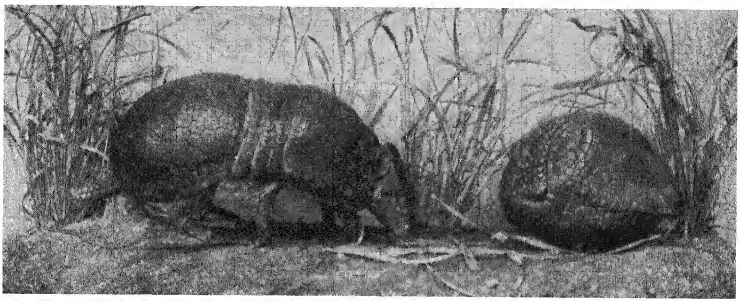


FIG. 175. When disturbed, an armadillo rolls itself into a ball that exposes only the armor to the enemy. (Chicago Museum photo)

The adaptations that plants and animals have for protection can be compared to those used by man to protect himself in time of war. First come the different kinds of armor and other defenses that prevent injury. Most important to animals in this connection is the skin and its adaptations. Practically all animals, except the very simplest kinds, have an outer covering that is much tougher than the inner parts and thus protects the soft inner organs. Many bacteria, fungi, and small parasites are kept from injuring animals because of this barrier.

Attached to the skins of many animals are structures that make the skin even more effective in preventing injuries. Fish, lizards, and snakes have scales on their

Fig. 176. One can hardly distinguish the stripes of the tiger from the lights and shadows of the jungle. (Ewing Galloway photo)

skin. Alligators and armadillos have a strong armor of horny plates. The porcupine has a skin covered with sharp "needles" that stick into the dog or man who ventures to touch him.

Turtles have a solid shell to protect the body from an ordinary attack. Some can even draw their heads and legs inside the shell. Snails and clams also have shells into which they can retreat from danger. Crabs, crayfishes, and insects have their skeletons on the outside of their bodies, so that the hard parts not only serve as a framework but protect the internal parts from injury. Thus we find that all but the very simplest animals have protective walls around their bodies.

But the skin and its covering have protective value in still another way. A great many animals are camouflaged. They are not easily seen by other animals. This *protective coloration* is very common. You do not need to go far to find examples. A gray rabbit sitting in a clump of grass or a quail brooding her eggs on the ground will usually be passed unnoticed. Deer are very inconspicuous

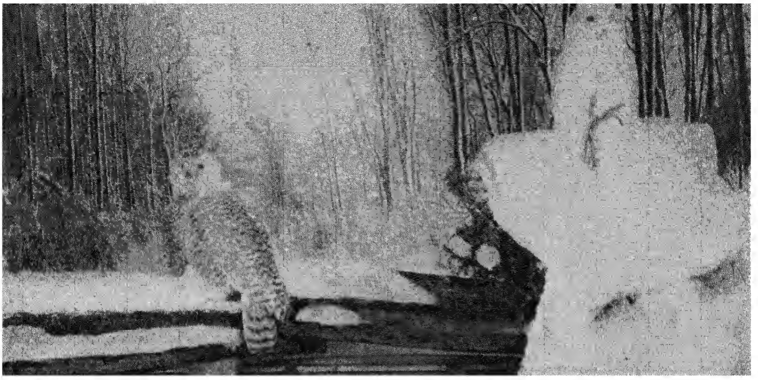


FIG. 177. In winter the feathers of the snowy owl change from spotted to white to match the wintry surroundings.

in the shadows of the forest. Many leaf-eating insects and caterpillars are green. Grasshoppers are mottled and inconspicuous in the half-dead grass of midsummer.

If you study animals, you will notice that as a rule the undersides of animals are lighter in color than the upper sides. Even though some of them, such as the sloth and an insect called the backswimmer, have taken to traveling upside down, their lower sides are lighter colored. Viewed from beneath, against the light of the sky, such animals are not prominent. Seen from above, their dark upper sides blend into the surroundings. Seen from the side, no conspicuous shadows show on their bodies.

FIG. 178. A tree frog (L. W. Brownell photo)

In regions that have long winters with much snow, animals change color with the season. Among these are the Arctic hare, weasel, lemming, and ptarmigan. In the summer they are gray or mottled, as are most animals of their kind. In the

FIG. 179. The spotted eggs of the killdeer blend in with the gray and white pebbles around them. (L. W. Brownell photo)

winter they get a new coat of white to harmonize with their snowy surroundings. A few animals, such as the chameleon and the tree frog, are able to change the color of their skins within a short period of time, so that they cannot be easily seen whether they are on green leaves or on gray bark.

Some scientists have doubted that protective coloration has any value for animals. However, recent experiments show that it really helps. One man found some small fish that were colored almost like the dark bottom of the pool where they lived. He had others of the same kind that had been living in water where the bottom was light-colored. They, too, were almost the color of their home; that is, they were lighter in color. He put equal numbers of the two kinds in a pool with a light bottom. Then he borrowed a couple of penguins from the zoo and gave them a picnic catching the fish. After a time he took the penguins away and counted the fish to see how many had been caught and eaten. The penguins had eaten more of the dark-colored fish.

Just to make sure that he was right in his conclusion, as scientists must be, he reversed his experiment. To do this, he put equal numbers of light-colored and dark-

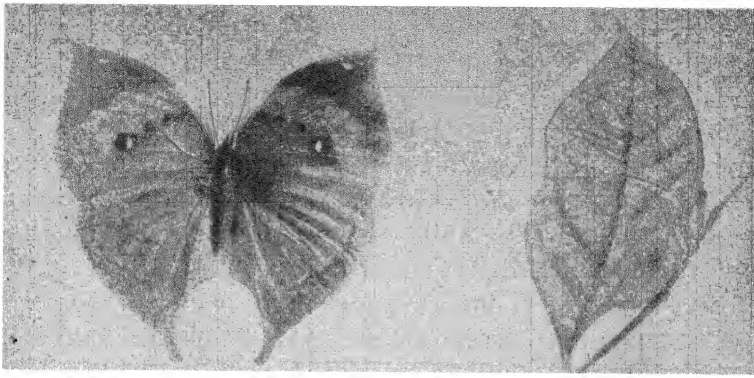


FIG. 180. Probably the most perfect example of mimicry is the Kallima butterfly of India. When the insect is flying, it is very conspicuous; but when it alights, it folds its wings and appears for all the world like a dead leaf, even to veins. (American Museum photo)

colored fish in a pool with a dark bottom. Then he gave the penguins another picnic, and again the fish that were not adapted in color to their surroundings were the ones that got caught in largest numbers. Most of the fish caught by the penguins were light-colored. These experiments seem to show that color can really be a protection.

A different method by which animals secure protection is to look like some other animal. This close resemblance of an animal to a different animal is called *mimicry*. A common butterfly, the viceroy, looks much like (mimics) the monarch butterfly, which birds do not like because of its disagreeable taste. A few harmless flies look almost exactly like bees. Some insect larvae, called "measuring worms," when at rest or disturbed, take positions on small branches so that they look just like twigs. The walking-stick really looks like a small stick.

Animals have still other ways of avoiding the notice of their enemies. Many of them feed at night, when there is little light for them to be seen. Then they hide in dens or thickets during the day. They build their nests and rear their young in secluded spots or in holes in the ground. Animals are also protected by having keen eyesight and

hearing and an acute sense of smell. With these they can often discover an enemy before they themselves are seen or attacked. The ability to run or to fly rapidly then helps them in making their escape.

There are times, however, when it is better to fight than to run away. Then offensive weapons are valuable. Horses, donkeys, and ostriches are able to drive off attackers by kicking them. Cattle and their relatives have horns. Wild boars have special teeth, called tusks, for defense. Birds use their beaks; bees and wasps use their stings. Snakes use their fangs or squeeze their victims to death. Of course, most of these weapons may be used for food-getting, but they all have great protective value. In many cases their chief use is for protection.

FIG. 181. A sea-horse that resembles sea-weed (American Museum photo)

HOW ARE PLANTS PROTECTED AGAINST BEING EATEN? Plants cannot move about; so they are less able to defend themselves than animals. However, many plants are well protected against both animals and other plants, such as fungi, that would use them for food. Just as in the case of animals, our common plants have a protective covering, the epidermis, the cells of which are tougher than the cells beneath. The bark of trees prevents many injuries to the delicate tissues beneath it. Some plants have an unpleasant taste or odor; some

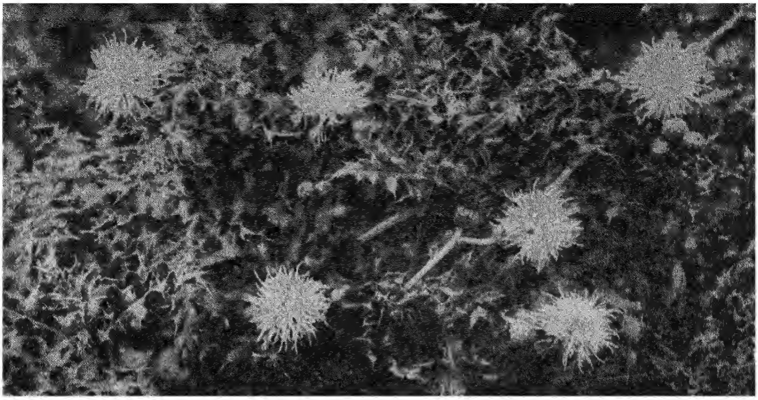


Fig. 182. Thistles have prickly leaves that help to protect the plants from animals that might otherwise eat them. (L. W. Brownell photo)

are even poisonous. The plants with structures that best protect them are usually very prominent in pastures where horses and cattle have eaten the poorly protected plants. Wild roses, small thorny bushes, thistles, ironweeds, and the hairy mullein stand almost or quite uninjured by the animals.

Have you now come to see that the world of living things is not entirely the peaceful, easy-going place we sometimes imagine it to be? There is a constant struggle to get food—to eat without being eaten. Some animals and some plants are constantly being destroyed by others. The ones that are just a little better protected than the rest are able to survive in larger numbers. Those plants and animals that are least easily seen, least tasteful, or best protected by armor or weapons are in many cases the ones that will continue to live. If conditions of soil and moisture are favorable to their growth, they will be the plants that produce the next generation in greatest numbers.

Self-Testing Exercises

1. State the three general ways in which animals are protected from enemies. Give an example of an animal that is protected in each way.

2. Describe the experiment that was done to learn the true value of protective coloration.

3. Name several ways in which plants keep from being eaten by animals.

Problems to Solve

1. Find a well-pastured field and notice carefully what plants have not been eaten by animals. Try to find out why in each case.

2. Do insects attack the plants that cattle and horses will not eat?

3. What plants most successfully resist being destroyed by man? Study the lawns in your locality. Look also in paths and places where plants are beaten down. Collect and identify the kinds that seem best able to survive. Try to find out why they survive.

Problem 4:
HOW DO WE FIT OUR ENVIRONMENT?

In what kind of habitat do we live? As you have read about the adaptations of plants and animals, have you been thinking how you and your friends are fitted to the surroundings in which you live? Like other living things, man must be adapted to his habitat, or he cannot live. Let us first see what his habitat is.

Of course we all know that man lives for the most part on land. But think for a few moments of all the countries you have studied in geography. How different they are! Some have tropical forests, some are cold, barren wastes covered with ice and snow much of the year, and some are hot, dry deserts. Some have large areas of mountainous territory, and others are level plains. Many places have a medium amount of moisture and a mild temperature. But in all these different kinds of places we find men living, getting food, and raising their families. Few other living

things, except some of man's own parasites, can be found in so many different kinds of places. We know that man must in some way be fitted to these different conditions. Our problem now is to learn how man can live under such widely different conditions when most other animals cannot.

Ceylon are expert at climbing the tall, slender coconut palms. (Ewing Galloway photo)

WHAT ARE THE ADAPTATIONS OF OUR BODIES? As you read Problems 2 and 3, you could hardly have helped noticing how your own body is, or is not, suited to the different kinds of conditions. In the first place, you are quite well fitted for getting about. You have a strong skeleton that supports your body. Movable legs with broad feet enable you to walk about on the land, although, to be sure, you cannot run as fast as many animals. In addition to having feet for walking and running on the ground, you have grasping hands with which you can climb. Later in this problem you will see that these hands are more important than they at first appear.

For protection from dry air, bacteria, and insects you have a fairly tough skin. For getting air into your blood you have lungs lined with thin membranes that would cover your body fifty times. You have a voice to send sounds through the air and ears to hear the sounds. You have eyes with which to receive light from things around us. You have smelling organs that detect odors quite well,

although, as you know, they are not so acute as those of some animals.

Like the bodies of birds and other mammals your body keeps itself at a certain warm temperature. The sweat glands pour out moisture and cool you by evaporation when you get too warm. However, you lack a thick insulating covering of hair, feathers, or fat to retain heat in cold weather. As you will soon see, you make up for that lack of adaptation by borrowing from plants and animals.

It is very important that our bodies be as well fitted to land life as they are. But that does not explain why we can live in most parts of the world. This is due to three important facts: (1) Man can eat a great variety of foods; thus he can find plants and animals to eat in almost every part of the earth. (2) Man has hands that can hold objects and handle them with great accuracy; thus he is able to use sticks, stones, tools, weapons, and all sorts of things to help himself keep alive. (3) Man has a brain with which he is able to think better than other animals; his brain directs the use of his hands. By using his hands and his brain, man (*a*) turns the adaptations of plants and animals to his own advantage, and (*b*) changes his environment to make it more favorable. Let us see how he does these two things.

HOW DO WE USE THE ADAPTATIONS OF PLANTS AND ANIMALS? You have already seen that man lacks an insulating covering to protect his body in cold weather. Long ago men noticed that the fur of animals kept them warm. As a result, they saved the skins of the animals that they killed and made coverings or clothing for themselves. Then they learned that they could make clothing from wool and from parts of plants that were fitted for this purpose.

FIG. 184. Men are able to live in the coldest regions of the world because they can use animals for food and the fur and skin of animals for warm clothing. (Ewing Galloway photo)

Another kind of adaptation that we turn to our own advantage is that for producing and storing food. Early man noticed that the milk from cows and goats was good food. As a result, he keeps many of these animals just for their milk. Man found out also that the eggs of birds contain a fine store of food, and he learned to keep the large birds that we call poultry for the eggs they lay.

In plants man found food stored in seeds, roots, and stems as an adaptation to the needs of the plants themselves. But he turned this store to his own use and began to cultivate the plants that stored the largest amounts of good food. Nor is man satisfied to use only the plants that grow where he is: He searches the whole world for plants and animals that are better adapted. He hunts plants and animals that are more resistant to disease than the ones he has. He searches for plants and animals that produce more and better body coverings and food. Then if they are adapted to his habitat, he brings these new varieties to his home and grows them there. If they cannot live where he is, he lets them live in their own habitat and carries their useful products to his home.

FIG. 185. Thousands of years ago man began to use animals to help him in his work. The dogs he used for hunting were the first animals that he domesticated. (Chicago Natural History Museum © photo)

But man does not stop with using the adaptations of other living things as he finds them. He improves the wool-producing ability of sheep, the milk production of cows, the egg laying of hens. He develops wheat that yields more grain, fruit trees that bear more and better apples and oranges, potatoes that are more resistant to blight and scab diseases. In Unit 10 you will learn some of the ways in which man is able to bring about these better adaptations of animals and plants to his needs.

HOW DO WE CHANGE OUR ENVIRONMENT TO FIT OUR NEEDS? A group of people are traveling into an uninhabited region in the Northwest. Night falls. What do you think the men do? They erect a tent or a crude shelter and build a fire so that they can be dry and warm during the night. One family decides that this region would make a good home. They build a log cabin with a fireplace, clear away the trees, cultivate the soil, and plant vegetables and grain. As their crops grow, they keep on cultivating the soil. What these people have really done by building shelters, having fires, and clearing and cultivating the soil

is to change their environment until it is better for them to live in. The house with a fire in it is a warmer, drier place than the outdoors. Furthermore, the house protects the family from dangerous animals and from annoying insects. Clearing the forests away and cultivating the soil changes light, moisture, and soil conditions so that the crops can grow better.

What are some of the other ways in which man changes the environment? He kills carnivorous animals, such as wolves, coyotes, and mountain-lions, that destroy the animals he wishes to keep. He drains wet, marshy land so that he can farm it. He builds new land at the margins of lakes and oceans, where he wants more room for buildings and parks. In other places he digs canals and builds dams to produce new waterways, new bathing, boating, and fishing places. Dams, canals, and tunnels carry water from bountiful rivers to dry land, where the soil will grow crops. If the soil lacks the right minerals or humus, he fertilizes it.

In all these ways man changes his environment so that he thinks it is better. By means of his hands and his thinking brain he does it. But sometimes he does not look far enough ahead when he begins to cultivate the soil, to kill off wild animals, or to import plants and animals. On sloping land the soil washes away. Herbivorous animals sometimes increase until they destroy the plants and then starve. Some imported plants and animals become pests of which we cannot rid ourselves. When men drain the marshes and cut down the forests to make farm lands, they deprive wild birds of shelter and food. When men build houses in which to live, they shut out the sunlight that is so necessary to their health.

It seems necessary and wise to make some of these

FIG. 186. Pioneer farmers in forest regions had to change their environment by clearing away the trees before they could grow their crops. (Ewing Galloway photo)

changes in the environment. But when they are made, scientists and historians should be consulted to learn, if possible, what the probable results will be. Lands that should not be cultivated or too heavily pastured should become government property. Then their use can be properly managed to prevent loss to future generations of our citizens. As you know, thousands of years are required to rebuild good soil after the original soil has been washed away.

Self-Testing Exercises

1. How does the size of man's habitat differ from the size of the habitat of most other living things? What are some of the reasons for this difference?

2. (*a*) List the structures of your own body that are adaptations to land life similar to those of some common animal. (*b*) List adaptations of your body that are different from the animal you have chosen.

3. Name three adaptations of plants and animals that man uses for his own good.

4. (*a*) How is your own environment different from the natural environment where you live? Make as long a list of differences as you can. (*b*) Do you think that you could keep alive in the natural environment of your region for a whole year without changing the conditions around your body? Give reasons for your answer.

Problems to Solve

1. How do animals change the conditions of their environment to make it more favorable? Think of bees, beavers, etc., and make as long a list as you can.

2. How do plants change the conditions of their own environment where they grow in large numbers? Think of light, moisture, and soil conditions.

3. How are social animals better adapted to their surroundings than solitary animals? (See *Book 1*, pp. 390-395, and other reference books on social animals.)

LOOKING BACK AT UNIT 3

1. State in complete sentences the ways in which your ideas have changed during the study of Unit 3.

2. Write one paragraph that answers Problem 1 of this unit. Then do the same for each of the other three problems.

3. Show that you understand each of these words.

adaptation	*habitat*	*migration*
mimicry	*hibernation*	*phosphorescent organ*
gill rakers	*lenticel*	*protective coloration*

ADDITIONAL EXERCISES

1. Read about the dinosaurs and other animals of ancient times. Find ways in which they were adapted to land, water, and air. Why do you think they disappeared?

2. The adaptations of fish described in this unit are the ones most common among these animals. Find articles in encyclopedias and other reference books and discover unusual adap-

tations. For example, the electric rays and eels have an unusual method of defense and food-getting.

3. Read about the migrations of one or two of the following animals: Pacific coast salmon, Arctic tern, golden plover, eel. Discover, if you can, how these migrations are helpful to the animals.

4. Make a special study of parasitic animals or plants. Find how each one is adapted to the life it leads.

5. Show how the behavior of plants and animals is one kind of adaptation.

6. Most common, broad-leaved trees shed their leaves in the autumn and get new ones in the spring. Is this an adaptation or not? Give reasons for your answer.

7. Pines and similar evergreen trees do not shed their leaves for winter. How are their leaves different from most other trees? What advantages do these kinds of leaves have?

8. Some scientists believe that small herbaceous plants are better adapted to life in temperate regions than trees. What advantages do they have? What advantages do trees have in getting what they need and in overcoming the dangers of their surroundings?

9. What kinds of plants live in the polar regions and in the highest mountain regions? Why do you think these kinds of plants can survive when others cannot?

10. Is man better adapted to live without fire in warm countries, temperate countries, or cold countries? Give your reasons.

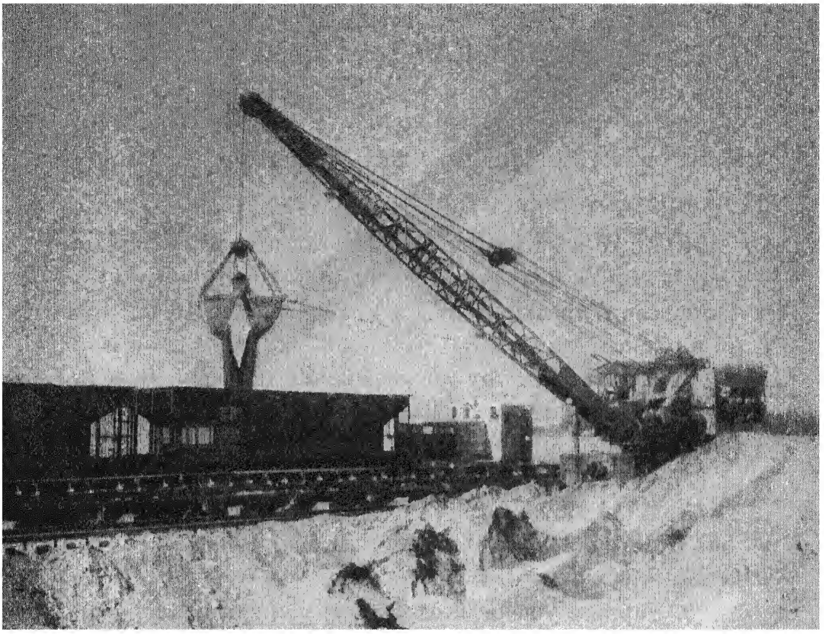


FIG. 187. Using the energy of exploding gases instead of the energy of human muscles, this machine does in one day the work of hundreds of men. It is a complicated machine with hundreds of parts. Yet, strange as it may seem, this complicated machine is made up of only four or five kinds of simple machines such as you probably use every day. In this unit you will learn that no matter how big or complicated a machine may be, it is made up of only a few simple machines that you have known about almost ever since you began to play with toys. You will also learn just how and why these machines help people do work. (Empire photos)

UNIT FOUR

UNIT 4

HOW DO SIMPLE MACHINES HELP US DO WORK?

INTRODUCTORY EXERCISES

*1. Make a definition of the word *energy*. Explain why the following have energy: (*a*) a bent bow, (*b*) a "wound-up" clock spring, (*c*) a weight lifted to the top of a pile-driver.

*2. Explain (*a*) why an automobile does not stop as soon as the brakes are applied, and (*b*) why you are jerked forward when an automobile stops suddenly.

*3. Tell in your own words what "force" means.

*4. What force do you overcome when you lift a heavy box from the floor to the top of a table? When you drive a nail into a piece of wood?

*5. Suppose you push as hard as you can in trying to move a heavy box, but cannot move it. Have you done any work? Make a definition of work to fit your answer.

6. Suppose that a weight heavier than you could lift had to be placed on the stage of the auditorium of your school. Name several ways in which you could get the weight there. What devices would you use? Tell how you would use them.

*7. What is friction? Tell how friction helps or hinders us in our work.

8. Make a list of ten or more simple devices that you have seen in use, such as an automobile jack, a screw driver, pliers, etc. After each device write a sentence telling how it helps us do work. Save your list for later use.

9. What is a simple machine? Explain your answer. Save it for later use.

10. Tell how a small boy can balance a much larger boy on a seesaw.

FIG. 188. This drill is a machine just as much as an engine is a machine. (Kaufman-Fabry photo)

FIG. 189. By cutting materials, both the drill and the saw help man do work. (Starek Studios)

LOOKING AHEAD TO UNIT 4

WHEN YOU saw the title of this unit, you probably thought of such machines as gasoline engines, sewing machines, reapers, steam engines, and electric motors. But if you read the title again, you saw that it said *simple* machines. Perhaps you changed your mind, then, and thought of lawn mowers, food choppers, and can openers. If you did so, you were still guessing. The simple machines of science are different from what you think.

As you already know from your study of science, the scientist is very much interested in finding the ways in which things are alike and the ways in which they are different. Things that are alike in one or more ways he puts in a certain group; then he uses some word to stand for this group. The scientist uses the word "machine" for any device or tool that man uses to help him do his work. A gasoline engine is very different from a screw driver. They do not look alike in any way. But they are both used by man to help him do this work. So the scientist calls each of them a machine. If you look around you, you will probably find that you can name fifty or more machines.

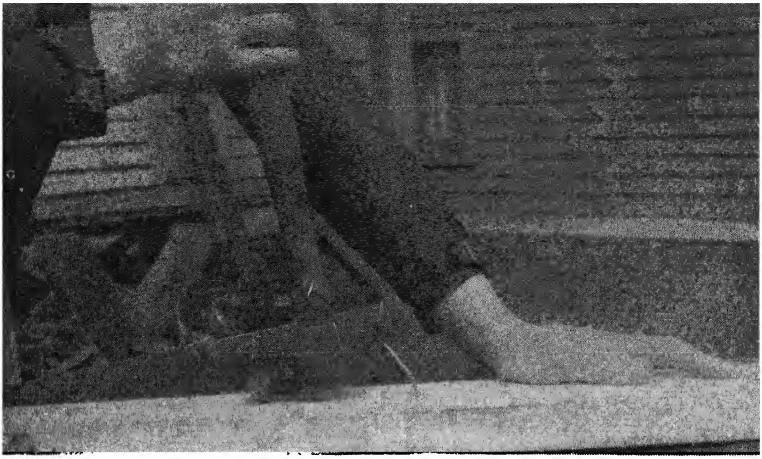


FIG. 190. When a hammer drives a nail into a board, it is one kind of machine. When it is used to pull the nail out, it is another kind of machine. (Starek Studios)

However, the scientist sees that machines are quite different in the way they work. So the scientist goes one step further and puts together into one class the kinds of simple devices that work alike. For example, most can openers and bottle openers really work just like a crowbar, or a hammer pulling a nail, or the jaws of a pair of pliers. The scientist therefore puts all of these devices and many others into a single class of simple machines that he calls *levers*. When you learn how a lever works, you can then explain how any of the many kinds of levers work. You can see that this makes your study much easier. Once you learn how a certain class of machine works, you can then see how all machines that belong in the same class operate.

In this unit you will learn that scientists have divided all simple machines into six different classes. When a scientist speaks about simple machines, he means a machine that belongs to one of the six classes that you will learn about. Hundreds of tools and devices that we use can be explained if you understand how each of these classes of machines helps man in his work. The more

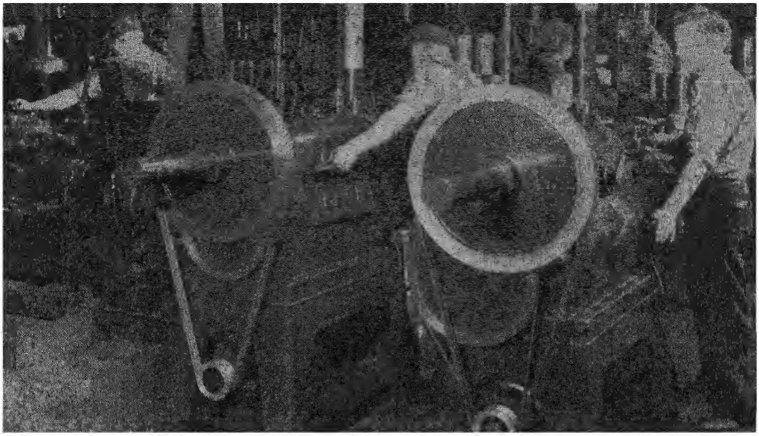


FIG. 191. Study the machine at the right carefully. Where do you think the power to run the machine is coming from? Then look at Figure 188. Is any part of the drill shown there at all like any parts of the machines shown on this page?

complicated machines, such as the crane, steam shovel, and printing press, are combinations of many simple machines belonging to different classes. But even these complicated machines can be explained by seeing how each class of simple machine helps in the operation of the complicated machine.

As you think about machines, you must be sure to keep one important fact in mind. We usually think of steam engines, gasoline engines, and electric motors as machines that do work and save our muscles. But it is really not the machine that does the work. It is the energy of steam, of gasoline, and of electric current that is doing the work. Without this energy the machines could do nothing. However, the special kinds of machines that help us use this energy are very important. In Units 8 and 9 you will learn how electric motors and engines work.

In this unit you will think chiefly about the simple machines that are put together to make complicated machines of all kinds. You will find the answers to questions that have come to your mind as you have watched work being done in various ways. You have probably seen a

Fig. 192. Shears are really two knives put together to make it easier to cut things.

Fig. 193. Probably every home has in it all of the six classes of simple machines that help people do work. It is likely that you have used most of them yourself.

man rolling a heavy barrel up a plank into a wagon. Perhaps you have seen *pulleys* used to pull up the stump of a tree or lift several bales of hay into a haymow. By himself a man could not lift the barrel or the bales of hay. But by using a machine he can easily move these heavy loads. In other words, he can lift objects that are very heavy by using a much smaller force. How is this possible? Do these machines really increase the amount of work that we can do?

What you learn about machines in this unit will be of practical value to you. Once you understand how a simple machine helps you, you can use it more intelligently. You will know what kind of work it can do and what to expect of it. You will learn how to select the kind of simple machine you need for the kind of work you want to do. Girls sometimes get the idea that machines are only used by boys. But that is not true. A girl may use simple machines in her home more often than a boy. Everybody uses machines. When you come to understand levers and the five other kinds of simple machines, you will recognize them all around you and even in your own body. You will also see that we would have a hard time getting along without them.

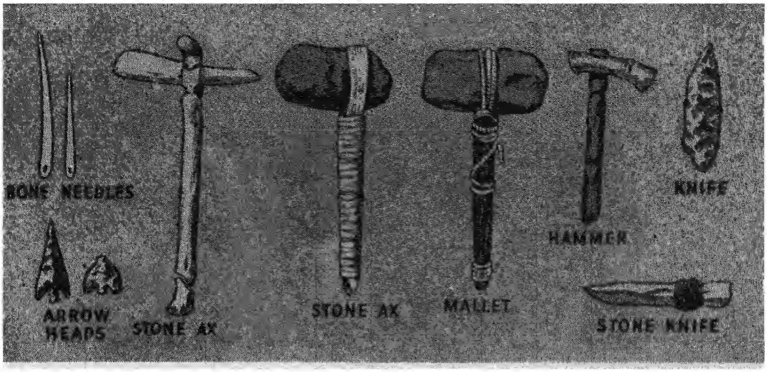


FIG. 194. The first machines that men used were clubs and hammers. Then came simple cutting and piercing tools made of bone and stone. No one knows who made the great discovery of how to use a wheel.

Problem 1:

WHAT ARE MACHINES USED FOR?

WHAT KINDS OF WORK DOES MAN DO WITH MACHINES? If you had lived many thousands of years ago, you would have done most of your work with your hands or with the simplest of tools. You would have had only a few flint knives, stone hatchets with crude wooden handles, bone awls for making little holes, and poles to pry with. Even in the time of Archimedes, almost 2000 years ago, you would have had few tools in comparison with the many kinds that are commonly used today. There is almost no end to their variety.

Think of the machines you have used today. If you came to school on a bicycle, you used a machine to help you move faster. When you opened a door, you turned a knob or pressed a latch. When you sharpened your pencil, a kind of machine helped you. Perhaps your mother asked you to help with the work about the house. What machines did you use? A can opener helped you cut metal, a knife helped you slice bread, an orange squeezer helped press the juice from fruit, and a broom or a vacuum cleaner helped you sweep the floor.

Think of the dozens of other machines that are commonly used in homes every day: clothes wringers, meat

FIG. 195. These men are using grinding machines to polish the bronze propeller of an ocean ship. Even the propeller is a machine. As it revolves in the water, it pushes the boat forward. It is called a *screw propeller* because it really works on the same principle as the common screw. (Nesmith and Associates photo)

grinders, pulleys for clothes lines, shovels for firing furnaces, scissors, tack pullers, ice tongs, tweezers, ice picks, and many others. It is hard to think of work in which machines are not used. A farmer uses axes, shovels, hoes, and rakes. Plows are used to break up soil, pitchforks are used for moving hay, pump handles help lift water from a well, and crowbars help lift heavy weights. Mechanics use pliers, hammers, screw drivers, wrenches, and cranks.

Hundreds of other machines are used in construction work, such as in building houses, roads, and bridges. Saws help cut boards, and hammers help drive nails to fasten the boards together. Screws and bolts hold parts of buildings together. Holes are bored with a brace-and-bit. Chisels are used to cut iron and other metals in two and to cut grooves in wood. Derricks are used to lift heavy objects and heavy loads of materials. Each of these machines is constructed to do a special kind of work. Some of them are used for cutting, others for lifting, and others for hammering. Imagine trying to build a house

FIG. 196. Natives of Nigeria, Africa, putting the roof on a house. Probably the only machines used in building this house were crude knives to cut the wood and crude shovels to dig the mud for the walls.

without tools! It would look more like the homes built by primitive men than like a modern house. The next time you build something at home or in the workshop at school, notice the different kinds of machines you use and think about how they help you.

Perhaps you are thinking by now that just about all the kinds of machines have been named. But before you leave this part of the unit, think of a few other important kinds of work that man does with machines. Suppose all of the materials we use had to be moved from place to place with our hands or carried on the backs of pack animals. Contractors would have a difficult time moving all the bricks needed to build a house. Trade would be slower because merchants could not get goods as fast as they needed them. Truck-farmers could not bring their produce to distant markets fast enough to keep it from spoiling. So machines are of great importance in transportation.

Perhaps the most complicated machines of all are used in the industries. Hydraulic presses are used in cotton gins to press the cotton into a small space. Roller

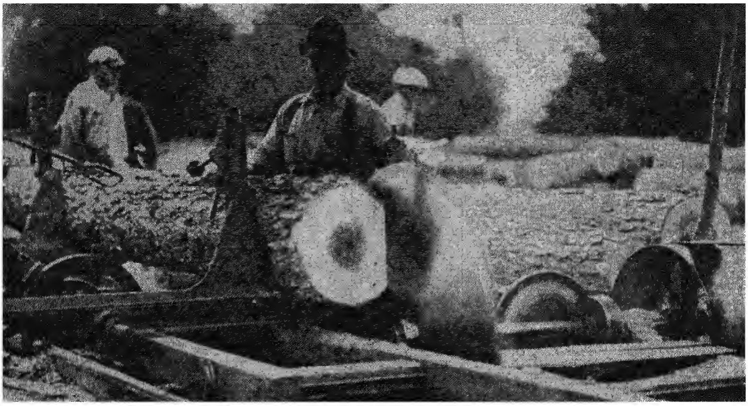


Fig. 197. Notice the use of wheels in this picture. At the right is a wheel with a belt to transmit the power from the engine to the saw. Wheels roll the carriage that pushes the log against the saw, and wheels with teeth in them help move the log sideways. Even the saw is a kind of wheel. (Eric G. Styrlander photo)

mills are used in iron and steel works to press metal into thin sheets. High-powered circular saws and band-saws are used to cut lumber in sawmills, and rapidly revolving blades (planers) give the lumber a smooth surface. Printing presses, trip hammers, and spinning and weaving machines are but a few of the kinds of machines that are used in industries to help man do his work.

WHAT KINDS OF RESISTANCE DO WE OVERCOME WITH THE USE OF MACHINES? Now that you have had a "rapid-fire" view of the many kinds of machines and the many different kinds of work they can do, let us try to see more clearly just what machines are used for. Each kind of machine that we use helps us to overcome some kind of resistance. There are only a few different kinds of resistance to overcome. What are they?

First of all, we use machines to overcome the force of gravity. Whenever an object is lifted by a machine, the force that runs the machine is lifting the object against the pull of gravity. You can think of many such machines.

Second, we use machines to start an object moving or

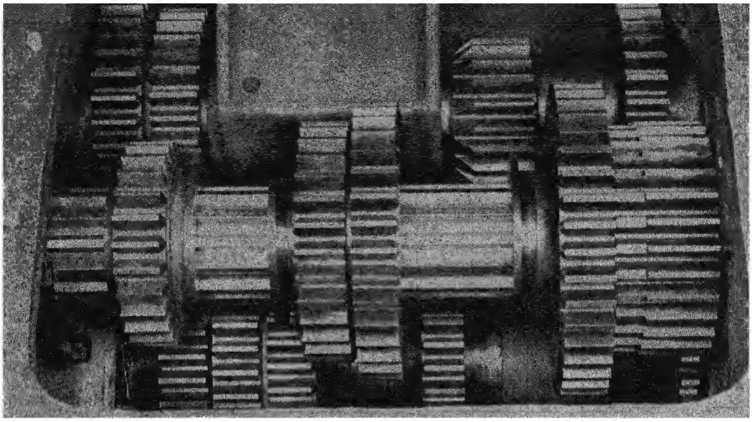


Fig. 198. Here is the gear box, or *transmission*, of an automobile. With one lever these gears can be moved to make the automobile go forward at three different speeds, and backward.

to stop it from moving. From *Science Problems, Book 2* you remember that materials have inertia; that is, they will stay in the same place or keep on moving in the same direction unless some outside force starts them, stops them, or turns them to one side. You use a baseball bat or a tennis racquet to overcome inertia whenever you hit a ball. The ball is suddenly stopped and started in another direction. In starting an automobile we use certain sets of gears ("low" and "intermediate") while the inertia of the car is being overcome. After the car is moving rapidly, we use a different and less powerful set ("high gear"). These gears are one kind of machine.

We use machines in a third way when they help us overcome the forces that hold the molecules of a material together. When you drive a wedge in wood (Figure 229), cut a board with a saw (Figure 189), or drive a nail, you are using a machine to force the molecules of the material apart, or to separate them from each other.

A fourth use of machines is to help us overcome friction. As you remember, whenever two materials are rubbed together, there is friction between them; that is, there is a resistance to the movement of one material over the

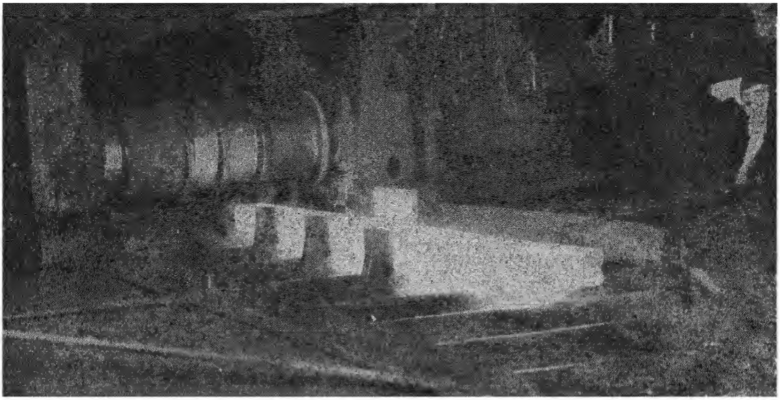


FIG. 199. To save the time and labor of cutting materials, men have invented power rolling and stamping machines to shape materials. Here white-hot steel is being squeezed into the desired shape. Even cold metals can be stamped into almost any shape. (Fox photos)

other. After an automobile is started, the energy of the engine is used to overcome the friction between the moving parts of the car, and between the air and the car.

Finally, we use machines to overcome the elastic forces in materials. We use machines each time we wind up the spring in a clock or watch. We use machines to compress elastic air into a small space and to press hay and light fluffy cotton into bales for shipping.

As you watch machines at work, you will probably notice many that are used to press materials together. For example, a clothes wringer presses the wet cloth together and squeezes the water out. A lemon squeezer does much the same thing. Printing presses force the inky type against the paper. Huge presses shape the fenders of automobiles from flat sheets and make coins from smooth disks of silver. These machines are overcoming elastic forces and the forces that hold molecules together.

In this problem you have seen that machines are used to overcome resistance of some kind. By their use we are able to do things that we could not possibly do with our unaided muscles. If you are not quite clear about the

FIG. 200. This short steel bar and a block of wood make a lever that is being used to lift a heavy block of concrete. (Starek Studios)

kinds of resistance that machines are used to overcome, read pages 231-239 in *Science Problems, Book 2*.

Self-Testing Exercises

1. Tell in your own words why it is often said that we are living in the "machine age."

2. List the machines that you have used today. After the name of each one, tell what kind of work it helped you do.

3. What machines would you need (*a*) to build a sailboat? (*b*) To help clean house? (*c*) To clean and repair your bicycle?

4. Write in a list the five kinds of resistance that machines help us overcome. After each kind write the names of at least two machines that help overcome that kind of resistance.

IN WHAT WAYS DO SIMPLE MECHANICAL DEVICES HELP US? You have seen what kinds of work machines can do. Now think for awhile about how a machine can be so helpful. Let us take a few examples of the uses of machines and see how these machines help us do our work. We will first suppose that there is a large stone in your garden and that you wish to move it. It is too heavy for you to lift. The easiest way to move it is to place the end of a strong pole under one side of the stone and a brick under the pole near the stone. Now if you push down on the outer end of the pole, you find that by using a rather

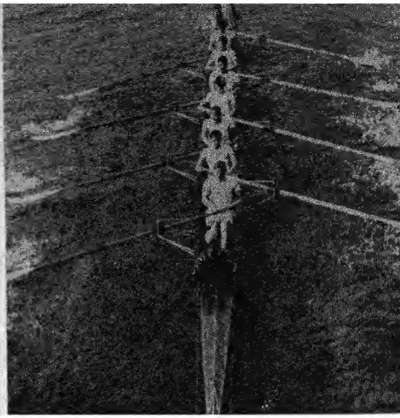


Fig. 201. Most kinds of nuts cannot be cracked without the help of a machine. The nutcracker multiplies the force of your hand. (Starek Studios)

Fig. 202. The men's hands and bodies move through only a short distance, but the ends of the oars move swiftly through many feet. (Ewing Galloway photo)

small force (as compared with the weight of the stone) you can easily lift the stone. How did this machine help you work? With the long bar you were able to lift a heavy weight (the stone) with much less force than you would have needed if you had used your muscles without the pole. This is one of the great advantages of a machine. With the help of a machine, we do not need to use so much force.

There are many kinds of machines used for this purpose. With the proper kind of jack, a small child can lift an automobile weighing thousands of pounds. Pump handles, claw hammers for pulling nails, nutcrackers, wheelbarrows, can openers, sloping planks, tack pullers, pliers, wrenches, and jackscrews are all simple machines by means of which we can use a small force to overcome a much larger resistance. This may be clearer to you if we say that with machines of this type we can multiply our force; that is, by using a force of ten pounds, a person can lift objects weighing a hundred or a thousand pounds.

Did you know that when you fish with an old-fashioned

bamboo fishing pole, you are using a machine? Let us see why a fishing pole is a machine and how it helps do work. Usually you hold the end of the pole in one hand next to your body. Then you pull on the pole with the other hand. Your hand only moves a few inches, but the other end of the pole moves many feet. Furthermore, it moves much faster than your hand, so that the fish is brought quickly above the surface of the water before it has a chance to get away. In this case the resistance or weight is moved farther and faster than the force. The machine has thus multiplied the distance traveled by the weight and the speed at which it traveled. Derricks used to lift and to swing loads from one place to another are machines that multiply speed (Figure 203). Your own arm, as you will see later, is a machine that works in the same way.

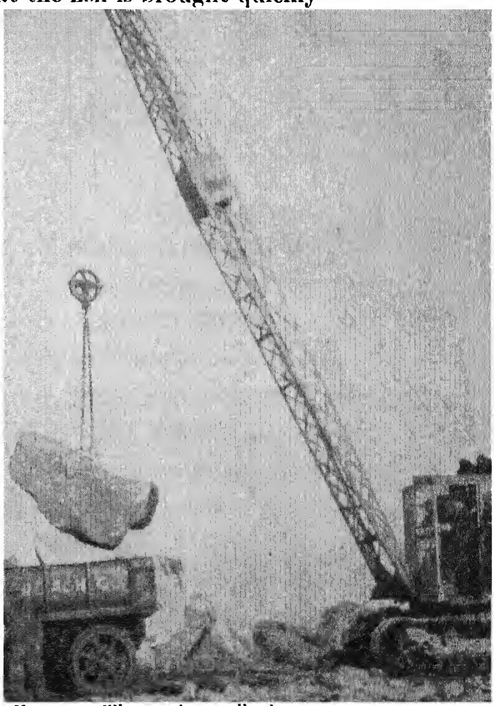


FIG. 203. The engine pulls down, but the rock moves up. Also, the lower end of the derrick moves through a distance of only a few feet while the upper end moves many feet. (Empire photo)

Still another way in which machines help us is by changing the direction of the force that is being exerted. Did you ever see a load of bricks being lifted to the top of a high building by a rope running over a wheel? This arrangement of

FIG. 204. By pulling downward on a chain this boy moves the load up.

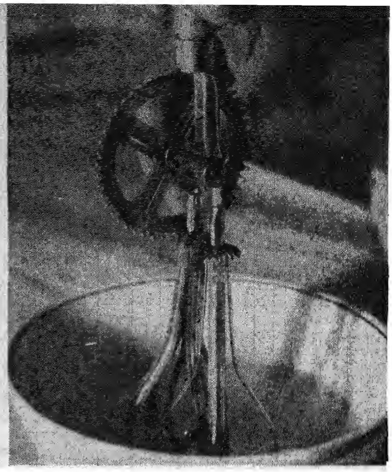


FIG. 205. Later in this unit you will learn how a big gear wheel like this multiplies speed.

a rope and a pulley (Figure 204) allows the person doing the lifting to stand on the ground and pull downward to make the load move up. The pulley changes the direction of force and makes it more convenient to lift the load.

A bicycle is another example of a machine that changes the direction of force; you push down on the pedals to make the bicycle pull you forward. The gear wheels in a rotary egg-beater make the blades turn in one direction as you turn the handle in another direction (Figure 205). As you study this unit, look for other machines that change the direction of the force.

Some mechanical devices, which are not usually called simple machines, help us in two other ways. In the examples of how machines help us, you have seen that the machine does its work only while the force is being applied. When you stop applying the force, the machine stops working. Some devices help us by storing energy. For example, a hammer is useful in driving a nail because the heavy head of the hammer gathers kinetic energy slowly from our muscles and then, in an instant, uses the

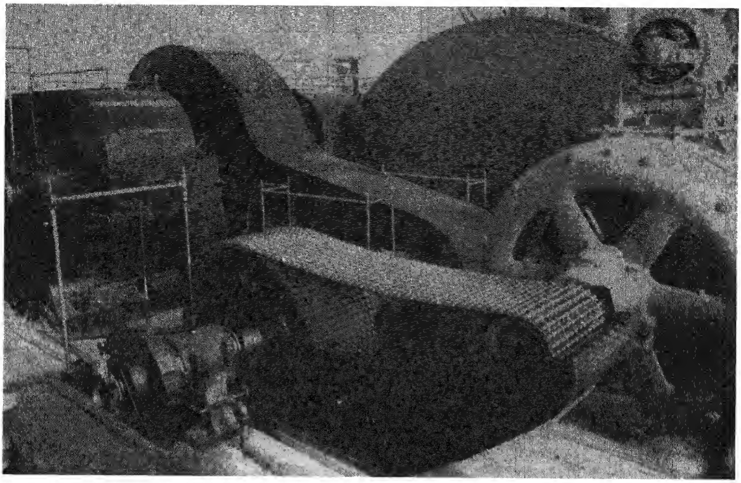


FIG. 206. This big *chain belt* transmits force to the electric generator at the right. Steam power turns the large wheel over which the belt runs. Chain belts, or *chain drives*, are much more efficient than leather belts. They are stronger, and they cannot slip.

energy to force the nail into the wood. Is it possible to store up energy that can be used after the force is no longer being applied? Think for a moment about a pile-driver used to drive piles into the ground. A steam engine, a gasoline engine, or an electric motor is used to supply the energy to lift a large weight high above the ground. As you learned in *Science Problems, Book 2*, the weight now has potential energy stored in it. When the weight is released, it will fall; when it strikes the pile, it drives the pile a short distance into the ground. The energy of the engine or motor was stored in the lifted weight.

Another example of a mechanical device to store energy is a spring. It takes energy to wind the spring. After the spring is wound by the energy of your muscles, it will give back this energy when it is released. The rubber band you use to drive your model airplane is another example of how a mechanical device may be used to store energy that can be released when and where it is needed.

In many machines it is necessary to provide some way

of transmitting the force from one place to another. For example, in an automobile the power is developed by the gasoline engine. To move the car it is necessary to transmit this force to the rear wheels. If you are familiar with an automobile, you know that this force is transmitted by shafts and gears under the body of the car. In the bicycle a chain is used to connect the sprocket wheel with the rear wheel. Belts are often used to transmit the energy of an electric motor to the various machines in a factory. With a pulley, as you know, a rope is used for this purpose. If you will look at a sewing-machine, the pulleys in a window, an egg-beater, or the vacuum-cleaner at home, you will find that each one has some device that is used to transmit force from the place where it is applied to the place where it is used. In Unit 9 you will learn more about how different devices are used for transmitting force and energy.

You can now see that mechanical devices help us do work in five important ways: (1) They may multiply our force. (2) They may multiply our distance and speed. (3) They may change the direction of the force. (4) They may store energy that can be released as we need it. (5) They may help us by providing a way to transmit force from one place to another place.

Self-Testing Exercises

1. Describe an experience of your own in which you used a machine to move a large weight with a much smaller force.

2. Make a diagram to show that in a fishing pole the force you apply to pull up the pole moves a much shorter distance than the fish. Also explain why the fish moves faster than your hand.

3. Make a diagram of some machine that you have used or seen that changes the direction of the force.

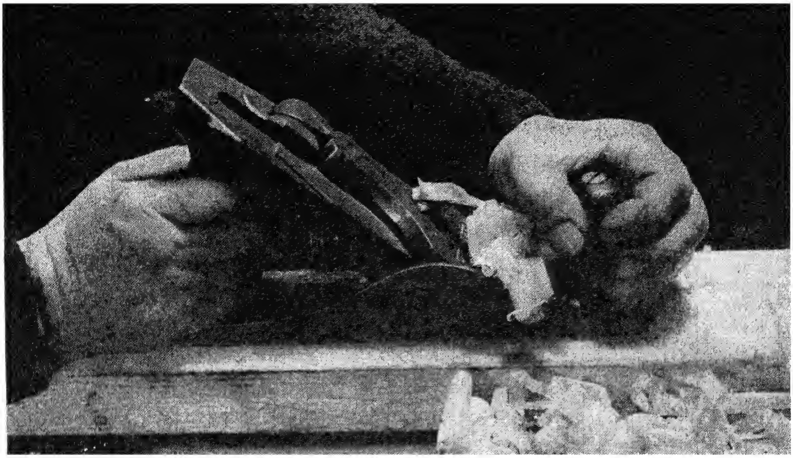


FIG. 207. Planes, draw shaves, and chisels are machines that help us to pull the molecules of materials apart. (Starek Studios)

4. When you cock an air gun, you compress air in the barrel. When the trigger is pulled, the compressed air forces the shot out of the barrel. Which use of a mechanical device does this illustrate?

5. Make a drawing to show how force is transmitted in some mechanical device.

Problems to Solve

1. How does a hammer help us to pull nails?
2. Get a toy operated by a spring. Find out how it works.
3. Examine a vacuum-cleaner. How is the force transmitted from the motor to the fan?
4. How is the energy from the mainspring transmitted to the hands of a watch?

Problem 2:
WHY DO MACHINES HELP US DO WORK?

HOW IS WORK MEASURED? If you have been thinking during your study of this unit, you have probably wondered *why* a machine makes work easier. You remember that when you studied about energy, you learned the law of Conservation of Energy. According to this law, energy is never made, and it is not destroyed. If this law is correct, you cannot get more work out of a machine

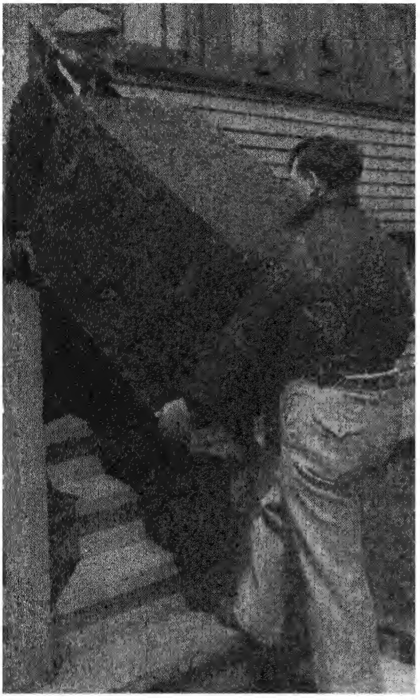


Fig. 208. You may think that these men are not using a machine to move the trunk. But the steps are really one kind of simple machine. They make it easier to lift things to higher levels. (Starek Studios)

than you put into the machine. Yet with a crowbar you can make a small force lift a large weight. This looks as if you were getting more work out of the machine than you put in. But this is not true. To understand just what the machine does, you must find some way of measuring the work put into a machine and then compare the work put in with the work that the machine does.

When you want to measure something, you must have some unit of measurement. For example, you measure distance by such units of length as the inch, the foot, the yard, the rod, and the mile. You measure the amount of heat in a body by calories. You measure the hotness of a body by its degree of temperature. In a like manner, we need a unit to measure work.

First of all, you must be certain that you understand what the scientist means when he uses the term *work*. To do work you must, of course, use force; that is, you must push or pull some object. Suppose that you lift a stone from the ground. You exert a force on the stone, and you lift the stone against the pull of gravity. The scientist would say that you have done work. Suppose,

however, that the stone was very heavy, and that although you used all the force you could, still the stone would not move. Would you call this work? You probably would, but the scientist would not. In order to do work, you must do more than use force. You must actually move the object. Work is done only when a force overcomes some resistance and thus moves something.

You do work when you pedal a bicycle, drive a nail, pull a sled, or lift a basket of groceries from the floor to the table. Some of these, riding a bicycle, for example, may have seemed more like play than work to you. But you did some work in each case. When you ride a bicycle, you overcome the friction of the bicycle wheels and of the air. When a nail is driven, the blow of the hammer exerts a force in making the nail push the fibers of the wood apart and move down into the wood. When you pull a sled, you move its weight a certain distance; and when you lift an object, you move its weight through a vertical distance from the floor to the top of the table.

In these examples of work nothing has been said about *how much* work was done. In other words, you have no unit to measure how much work is done when a stone is lifted from a floor. We usually measure force in pounds. If a stone weighs ten pounds, you must use a force of ten pounds to lift it. We measure distance in feet. According to our definition of work, the force must move the object through a distance. The amount of work done is therefore determined by how much force is used and how far the object is moved.

The unit to measure this is called the *foot-pound.* If a force of one pound is used to move an object through a distance of one foot, one foot-pound of work is done. Now you can measure how much work you do if you lift a stone

weighing ten pounds to a height of three feet. You multiply the force (10 pounds) by the distance moved (3 feet), and you get 30 foot-pounds. To find out how much work is done, it is only necessary to multiply the force by the distance moved. If you weigh 100 pounds and you climb a stairs 10 feet high, how much work have you done?

Self-Testing Exercises

1. Two teams were having a tug of war. Both teams were pulling with all their strength. Neither team could move the other. According to the scientist's meaning of "work," were the members of the teams doing work? Explain your answer.
2. Make up a problem to show that you understand the meaning of the term "foot-pound."
3. Which would do more work: a man who lifted ten 100-pound sacks of flour three feet in five minutes, or a man who lifted 20 fifty-pound sacks of flour three feet in ten minutes? Why?

Problems to Solve

1. Imagine that your friend is standing on a five-foot platform, trying to pull a fifty-pound box up to the platform with a rope. You get under the box and help by lifting it. When the box is four feet in the air, the rope breaks. You have to hold it where it is for two minutes until your friend can get down and help you lower it to the ground. How much work did you do during the two minutes?
2. A horse is pulling a wagon up a hill. Is the horse working? Finally the hill gets so steep that all the horse can do is keep the wagon from rolling down the hill. Is the horse working?
3. How could you find out how much work is done when a boat is pulled up on a beach for a distance of ten feet?
4. A bale of hay was lifted from a truck to a window seven feet above the truck. The hay weighed 85 pounds. How much work was done?
5. How much work do you do in climbing a ladder until your feet are 15 feet above the ground?

FIG. 209. In this picture the wagon and its contents weighed ten pounds. The force required to pull the wagon was $4\frac{1}{4}$ pounds.

DO MACHINES SAVE WORK? Now you are ready to see if a machine does really save work; that is, whether you can get more work out of a machine than you put into it. You already know that it is easier to get into a wagon by walking up a plank than it is to lift yourself into the wagon. You can roll a heavy barrel up a plank into a truck when you cannot lift it. Does it really take less work to roll a barrel up a plank into a wagon?

EXPERIMENT 7. *Does It Require Less Work to Roll an Object up a Plank Than to Lift the Object the Same Distance?* Get a smooth board five feet long and one foot wide. Place one end of the board on a support so that it rests two feet above the top of a table. Get a small wagon with wheels that turn easily. Oil the wheels. Add some iron weights or some stones to the wagon to make the cart and the weights weigh about ten pounds.

Attach a spring balance to the loaded wagon and pull it slowly up the plank at a uniform rate of speed. Have someone read the spring balance as you pull the load up the plank. How much force does it take to move the load? How much force does it take to lift the wagon and its contents? How does this compare with the force required to pull the load up the plank?

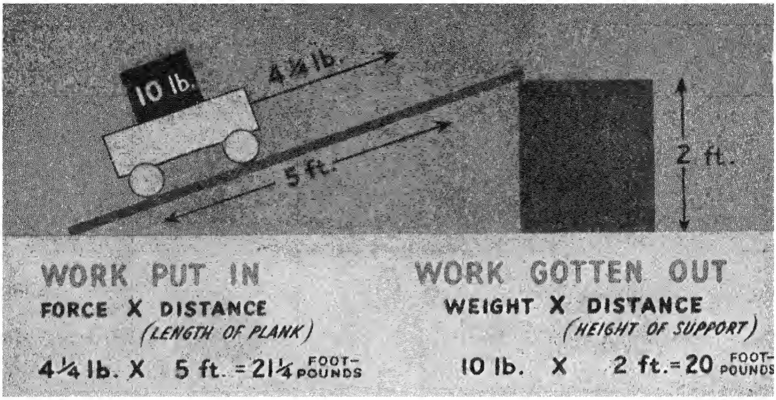


FIG. 210. This diagram will help you understand why an inclined plane helps do work but does not save work.

Now you can figure how much work was done in pulling the wagon up the plank. Let us suppose that it took a force of four pounds to pull the wagon up the five-foot plank. The work *put in* to the machine would be four pounds times five feet, or 20 foot-pounds. We will also suppose that the wagon and weights weighed ten pounds. It would be necessary to lift the wagon straight up for a distance of two feet to raise it the same height as it was when rolled up the plank. The work accomplished by the plank would therefore be ten pounds times two feet, or 20 foot-pounds. In other words, the work you put into the machine (rolling the wagon up the plank) is equal to the work the machine accomplished (lifting the wagon up for a distance of two feet).

Now use this same method to measure the work put in and the work done by the machine in Figure 209. How much work was done in pulling the wagon up the plank? To find this, multiply the force needed by the length of the plank. (See Figure 210.) How much useful work was accomplished? To find this, multiply the weight of the wagon and its contents by the height to which they were lifted. When you compare the amount of work actually done in rolling the wagon up the plank with the

amount of work required to lift the wagon, you find that you put more work into the machine than you actually got out of it. Why is this true? You remember that whenever two surfaces rub together, there is friction between them. In rolling the wagon up the plank, you not only had to overcome the weight of the wagon, but you also had to overcome the friction between the moving parts.

The answer to our question, Does a machine save work? is "No." There is always some friction in a machine; therefore more work is always put into a machine than is gotten from it. That is, you always do more work on the machine than the machine does for you.

Perhaps you have heard people say that a certain machine is very efficient. What does this mean? It means that we get almost as much work out of the machine as is put into it. For example, suppose that 100 foot-pounds of work are put into a machine, and 90 foot-pounds of useful work are accomplished. The efficiency of such a machine is 90 per cent. To find the efficiency of a machine, it is only necessary to divide the *work gotten out* by the *work put in*. You can now find the efficiency of the machine used in your experiment. Take the amount of work accomplished by lifting the wagon through a distance of two feet. Divide it by the amount of work done in pulling the wagon up the plank. What do you find?

Self-Testing Exercises

1. Answer the following questions regarding Experiment 7.
a) How much force was required to pull the wagon up the plank?
b) How much work was done?
c) How much force was required to lift the wagon?
d) How much useful work is done when the wagon is lifted up to the same height as it is rolled up?

FIG. 211. Suppose each bag weighs 100 pounds, and has to be lifted to a height of 5 feet. How many foot-pounds of work will it take to lift each bag? When these men carry the bags up the plank, do they lift them a greater distance than if they lifted them directly up on to the pile? Why is the plank used? (Ewing Galloway photo)

e) Which is greater, the work in or the work out? Explain.

f) What is the efficiency of your machine?

2. A certain machine is 50% efficient. What does this mean?

3. In actual use do we ever get as much work out of a machine as we put into it? Explain.

Problems to Solve

1. A barrel that weighs 200 pounds is lifted into a wagon three feet above the ground. How much work is done?

2. The same barrel is rolled up a plank ten feet long into the wagon. It is found that a force of 62 pounds is necessary. How much work was done in this case? What is the efficiency of this machine?

WHY ARE MACHINES ABLE TO EXERT SUCH LARGE FORCES? You are no doubt wondering, "If we have to put as much (or more) work into machines than we get from them, why should we use them at all?" This is a good question to ask. In answering it, think of the experiment again. You found that you used a small force to lift

a much heavier weight. For example, if the weight of the wagon was ten pounds, you found that you could pull it up the board with a force of four pounds. However (and this is the important point to see), you had to move the small force through a greater distance (5 feet) than if you had lifted the weight to the upper end of the plank (2 feet). In other words, to increase your force two and one-half times (10 divided by 4), you had to move the force through two and one-half times the distance the weight moved (5 divided by 2).

The advantage of using such a machine is that it is easier to move a small force through a greater distance than it is to move a large force through a shorter distance. For example, you could not lift a 200-pound barrel from the ground into a truck three feet from the ground. However, you might be able to roll the barrel up a ten-foot plank into the truck, because you would apply a much smaller force through a greater distance.

Perhaps you now understand how a small force can be used to lift a large weight: The small force must move through a longer distance. Also, you understand why machines do not "save work." The work we put into a machine equals the work we get from it (neglecting friction). We use machines because they make work easier.

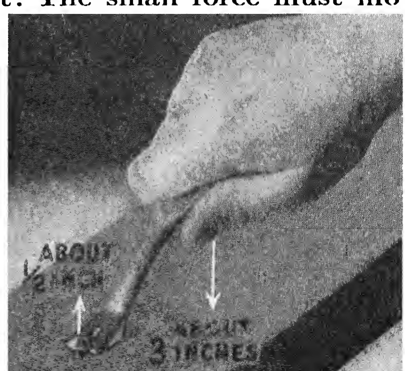


FIG. 212. Explain what this picture shows about this kind of machine.

There is a way of calculating how much help we can get from a

machine. We call the amount of help we get from a machine its *mechanical advantage.* Now let us figure out the mechanical advantage of the board you used in Experiment 7. You found that you could lift a 10-pound weight with a force of about 4 pounds. The mechanical advantage of this machine was $2\frac{1}{2}$ (10 divided by 4). So, one way of finding mechanical advantage is to divide the weight lifted by the force needed to lift it.

Suppose you wanted to lift the 10-pound weight in Experiment 7 with a force smaller than 4 pounds. How could you do it? You could use a longer board, for example, a board 10 feet long. This time the force would move 10 feet to lift the weight 2 feet. The mechanical advantage in this case would be 5 (10 divided by 2). In this example you used another method of finding mechanical advantage. You divided the distance the force moves by the distance the weight moves.

What would be the mechanical advantage of a machine in which the force moved ten feet and the weight moved one foot? You can easily see that the answer is ten. Here is an important point to remember: In any machine the greater the distance the force moves as compared with the distance the weight moves, the greater the mechanical advantage. You are now ready to find how other simple machines operate and why they are helpful.

Self-Testing Exercises

1. If more work is put into a machine than we get from it, why do we use a machine?
2. What does "mechanical advantage" mean?
3. If a machine can lift a weight of 100 pounds with a force of 10 pounds, what is the mechanical advantage of the machine?
4. Why can small forces lift large weights when a machine is used?

Problems to Solve

1. Suppose you have a barrel weighing 200 pounds which you want to lift three feet into a wagon. You can only exert a force of 50 pounds. How long a plank would you use?

2. If you used a plank 12 feet long to roll a barrel up into a wagon bed three feet high, what would be the mechanical advantage? If the barrel weighed 100 pounds, how much force would you need to exert?

Fig. 213. Apparatus needed for the first part of Experiment 8

Problem 3:

WHAT ARE THE KINDS OF SIMPLE MACHINES?

How do levers help us? Now that you understand what machines can do, you are ready to study the different kinds of simple machines. Scientists have classified all simple machines into six groups: the *inclined plane*, the *lever*, the *screw*, the *wheel and axle*, the *pulley*, and the *wedge*. When you use a pole to pry up a heavy stone, you are using the simple machine known as the lever.

Experiment 8. *How do Levers Work?* (*a*) Fasten a spring scale to the end of a strong, straight stick. The stick should be more than three feet long. Balance the stick and spring scale on a support about a foot above the table (Figure 213). Notice the reading on the spring scale when there is no pull on it. Hang a five-pound weight on the opposite end of the stick. Have the distance from the support to the weight equal to the distance from the spring scale to the support. Have two classmates each hold yardsticks vertically just back of each

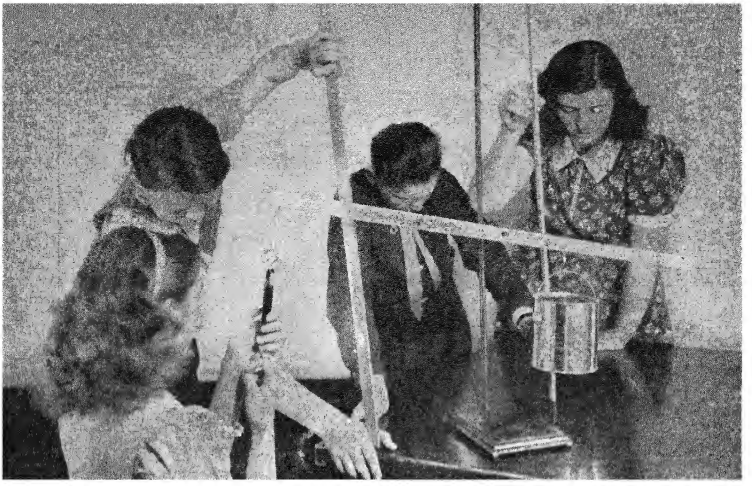


Fig. 214. Apparatus for the second part of Experiment 8

end of the balanced yardstick, but be sure they do not touch it.

Now pull downward on the hook of the spring scale until the stick touches the top of the table. (Let your hand and the scale move down past the edge of the table to do this.) How much force did it take to move the weight upward? How far did the weight move upward? How far did your hand move downward?

b) Now move the weight toward the support to make it only one third as far away as the spring scale (Figure 214). Pull down on the scale until the yardstick touches the top of the table. How much force did you use? How far did the weight move upward? How far did your hand move downward?

The place where a lever is rested or supported is called the *fulcrum*. The distance from the weight to the fulcrum is the *weight-arm*, and the distance from the force (your hand) to the fulcrum is the *force-arm*. In part *a* of the experiment you found that the force needed to lift the weight was about equal to the weight. In this case, the length of the force-arm was equal to the length of the weight-arm. When the force-arm and the weight-arm are equal in length, both arms move the same distance. Therefore, the distance the force moves is equal to the distance the weight moves, and the mechanical advantage is one.

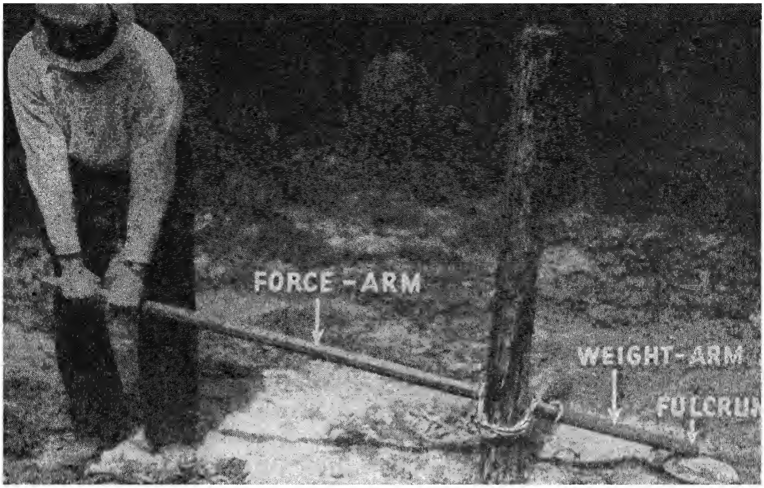


Fig. 215. In this home-made post-puller the lever is fastened to the post with rope. As the post is pulled higher, the rope can always be slipped down to get a new hold on the post. (Claude J. Dyer photo)

In part *b* of the experiment the force-arm was longer than the weight-arm. The force moved through a much greater distance than the weight, and, as you found, a smaller force could lift the weight. So, if you wish to increase the mechanical advantage of this kind of machine, you must make the force-arm as long as possible in comparison with the weight-arm. Then a small force can be moved through a greater distance to lift a large weight a smaller distance. For example, if you wish to pry up a heavy weight with a crowbar, keep the fulcrum as close to the weight as possible. Such levers make work easier because you use a small force to move a much greater weight. But remember that you do not save work, because you move the small force through a greater distance.

Suppose you wanted to pull a post out of the ground with a lever. You could not place one end of the lever under the post, as you did with the stone. You would have to fasten the post to the lever, as the man in Figure 215 has done. Then you would rest the short end of the lever on a block and lift upward at the other end. You would

FIG. 216. The everyday shovel is a lever. In this picture the fulcrum is where the hand grasps the end of the shovel, and the force is applied where the other hand grasps the shovel. (Fox Photos)

have to pull upward through a long distance to move the post a short distance.

Notice that the fulcrum is the point on the lever that does not move. The lever turns about the fulcrum. The fulcrum may be at the end of the lever or anywhere between the weight and the force. No matter where the fulcrum is, a lever multiplies force when the force-arm is longer than the weight-arm. Pliers, nutcrackers, tack pullers, and pump handles are levers that multiply force.

However, not all levers are used to multiply force. When the weight-arm is longer than the force-arm, we multiply distance and speed instead of force. In the fishing pole the fulcrum is at the end of the pole toward your body. You apply the force with the hand that is only a short distance away from the fulcrum. The fish attached to the end of the pole is the weight. It moves farther and faster than your hand. The crane in Figure 187, fire tongs, a ball bat, a pitchfork, and a broom or mop are all examples of levers that multiply distance and speed.

Notice that when the fulcrum of a lever is between the force and the weight, one end goes up and the other goes down, thus changing the direction of motion. Figure 200 on page 211 shows a lever that is changing the direction of motion, as well as increasing the force.

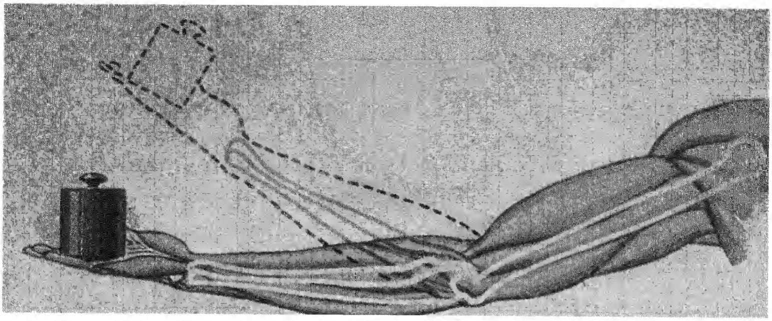


FIG. 217. What kind of advantage does the bone lever in your forearm give?

Self-Testing Exercises

1. Make a drawing to show how you could pry up a stone weighing 200 pounds by using a force of 40 pounds. What is the mechanical advantage of your lever? How does the mechanical advantage of your lever compare with the lengths of the force-arm and the weight-arm?

2. Explain why it is possible to lift a heavy weight with a small force by using a lever.

3. Make sketches to show the different ways in which the fulcrum, weight-arm, and force-arm may be arranged. Which ways multiply force? Which multiply speed and distance?

Problems to Solve

1. Keep a record of all the levers you can discover for yourself. After each one tell whether it is used to gain an advantage of force or of distance or to change the direction of force.

2. Suppose you were carrying a heavy bag on a stick over your shoulder. Would you keep the bag close to your shoulder or out near the end of the stick? Make a drawing and explain why.

3. Press down a key of a typewriter. What kind of machine is it? Make a drawing that will show whether you get an advantage of distance or of force.

4. Shears for cutting tin and metal have long handles and short blades. Shears for cutting paper have short handles and long blades. Explain why they are not constructed alike.

5. Would you place the load in a wheelbarrow near the wheel or near the handles? Make a drawing to explain your answer.

How do pulleys help us? When you open a window that has cords attached to it, you are using another kind of simple machine. The cords run over small grooved wheels, called *pulleys*, in the window frame. Did you ever see a farmer lift a load of hay into a barn by using a rope and pulleys? Perhaps you have used a pulley and have found that it made your work easier to do. There are two different ways of using pulleys to do work. An experiment will help you understand both ways.

Experiment 9. *How Do Pulleys Work?* (*a*) Fasten a single pulley three feet above the top of a table, as Figure 219 shows. Attach a strong cord to a pail of sand that weighs five pounds. Run the cord over the rim of the pulley wheel. Fasten the other end of the cord to the hook of the spring scale. Stand a yardstick on end behind the pulley so that you can tell how far the weight moves as your hand moves.

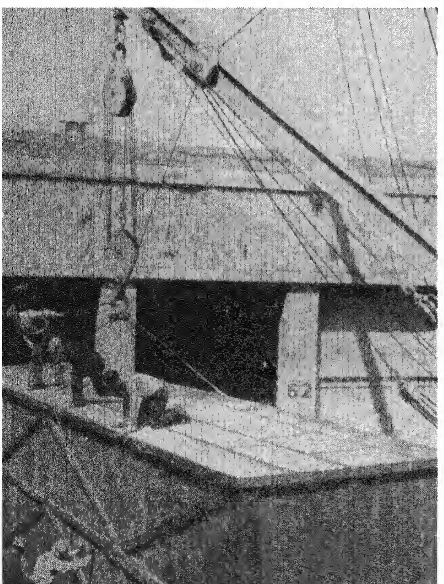
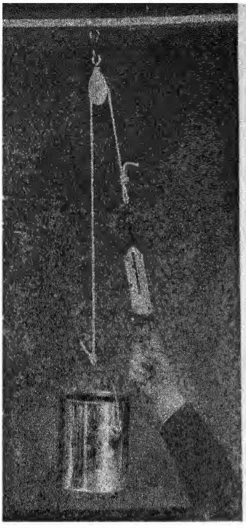
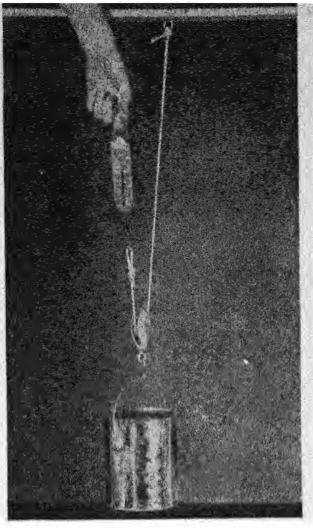


Fig. 218. Moving a heavy load with a crane and pulleys (Acme photo)

Hold the ring of the spring scale in one hand and pull downward at a uniform rate until your hand has moved one foot. How far has the weight moved? In what direction has it moved? How much force was registered on the spring scale in moving the five-pound weight a distance of one foot? What advantage is given by the pulley arranged in this way?

b) Rig up a pulley like the one in Figure 220. This time the pail of sand and the pulley together should weigh five pounds. Attach the





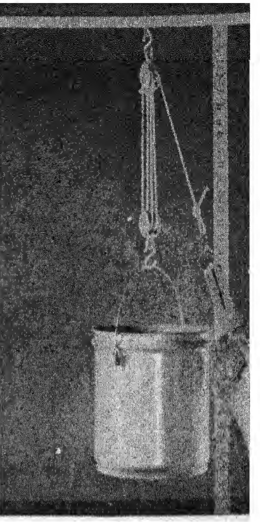


FIG. 219. A single fixed pulley

FIG. 220. A single movable pulley

FIG. 221. Block and tackle

weight to the pulley and lift upward on the ring of the spring scale. Move your hand upward at a uniform rate for a distance of two feet. How far has the weight moved? How much force was registered on the spring scale? How does this compare with the weight of the pail of sand?

c) Rig up a combination of pulleys, as in Figure 221. Use a pail of sand that weighs eight pounds. Hold the spring scale in your hand and move your hand downward at a uniform rate for two feet. In what direction did the weight move? How far? What did the reading on the spring scale show? How did this compare with the weight of the pail of sand?

In part *a* of the experiment you found that when you lifted the weight a distance of one foot, you had to move the force a distance of one foot. Also, the force that was needed to lift the weight was about equal to the weight. As in the case of the lever (part *a* of Experiment 8), the mechanical advantage of this kind of machine is *one* when we pay no attention to friction. A pulley arranged like this one is known as a *fixed pulley*. It is called a fixed pulley because it does not move up or down.

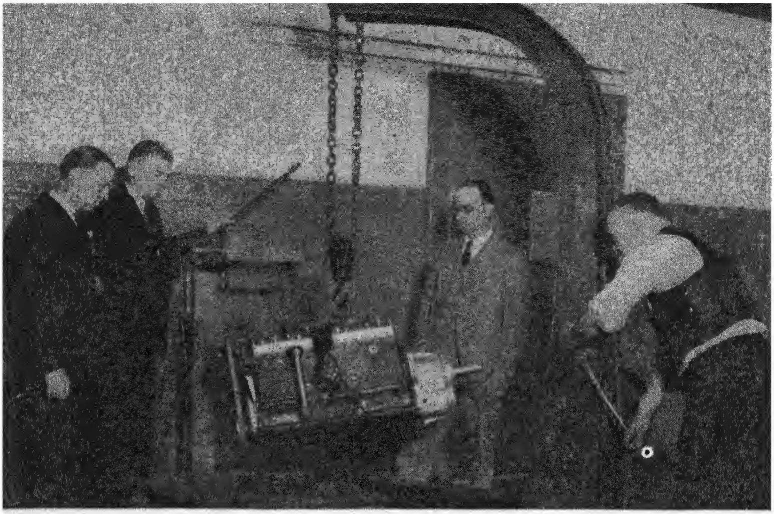


FIG. 222. Here is a convenient crane that can be moved around on wheels to any place where something is to be lifted. How many pulleys can you see on the crane? Are they fixed or movable? Are there any levers in this picture? Figure out how the direction of the force is changed by this machine.

Probably it does not seem to be of much help if you have to put as much work in as the work out. But a fixed pulley is of decided help in one way. Did you ever use a pulley of this kind to pull a flag to the top of a flag pole? It did not take much force to get the flag to the top of its very tall pole, but suppose the pulley had not been there. You would have had to climb to the top of the pole carrying the weight of your body and the flag with you. So the real advantage in using a fixed pulley is that it changes the direction of the force you use. This makes it convenient for you to get the flag in its proper place.

In part *b* of the experiment you used another arrangement of a machine: a *movable pulley*. As you pulled upward on the cord, the pulley moved upward with the weight, and your hand moved twice as far as the weight; so you lifted a five-pound weight with a force of two and one-half pounds. The mechanical advantage of a single movable pulley is *two* (when we pay no attention to friction).

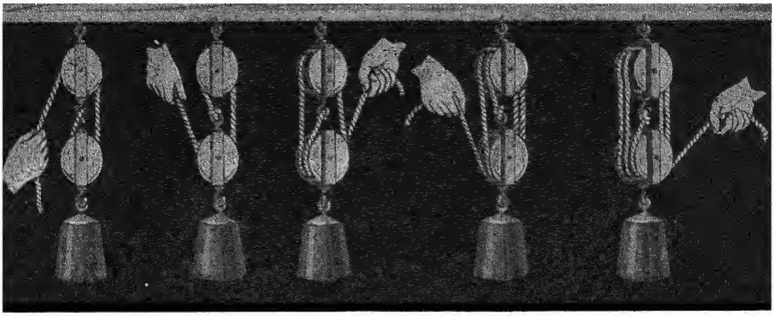


FIG. 223. This picture shows various ways in which pulleys may be combined to make work easier.

A combination of pulleys and a rope, known as a *block and tackle*, is most often used by workmen (Figure 218). In part *c* of the experiment you found that with a block and tackle arrangement you could lift an eight-pound weight by using only about two pounds of force (shown on spring balance). The force moved four times as far as the weight moved; so the mechanical advantage in this case was *four*.

Of course, there are many other ways in which combinations of pulleys can be rigged up (Figure 223). But the important thing to remember is this: The greater the number of pulleys used, the greater the mechanical advantage. This is true because the greater the number of pulleys, the farther the force must move to lift the weight a certain distance. When you see painters raising scaffolds or workmen lifting a piano with a block and tackle, you will understand how pulleys make work easier to do.

Self-Testing Exercises

1. Give an example of your own in which you have seen a single fixed pulley used. If you have not seen one, try to make up a situation in which you might use one.

2. Make a drawing that will show how you might use a block and tackle to lift a boat weighing 300 pounds out of the water. Assume that you can pull with a force of 60 pounds. If you lifted the boat four feet, how far would you have to pull the rope? What would be the mechanical advantage?

FIG. 224. With this machine the force moves in a circle to pull the pail in a straight line. (J. C. Allen photo)

HOW DO INCLINED PLANES HELP US? The plank you used in Experiment 7 was an *inclined plane.* You found that it took less force to roll a loaded cart up a plank than to lift the cart. You also learned why this was true. The distance the barrel is moved up the plank is much greater than the vertical distance the barrel is raised. It is easy to find what the mechanical advantage of an inclined plane is. All that is necessary is to divide the length of the plane by the height of the upper end. In other words, if a plane is 10 feet long and the distance the object is raised is two feet, the mechanical advantage is five (if we neglect friction). The longer the board used, therefore, the greater the mechanical advantage.

HOW DOES A WHEEL AND AXLE HELP US? Have you ever seen a device like the one in Figure 224 used to raise water from a well or to raise a ship's anchor or some other heavy weight? This kind of simple machine is a *wheel and axle.* An experiment will help you understand how wheel-and-axle machines make work easier.

EXPERIMENT 10. *How Does a Wheel and Axle Make Work Easier?* In your school workshop or at home, make a piece of apparatus like the one in Figure 225. Oil the bearings. Fasten a fifteen-pound bag of sand to a small nail driven into the axle. Adjust the apparatus so that when you pull down on the heavy cord attached to the rim of the wheel, the cord will roll

around the axle and lift the weight. Be sure to clamp the apparatus to the table.

When the apparatus is adjusted, pull down on the spring balance at a uniform rate of speed. What is the reading on the spring balance? Have two of your classmates hold yardsticks behind the weight and behind your hand. How far is the weight lifted? How far does your hand move?

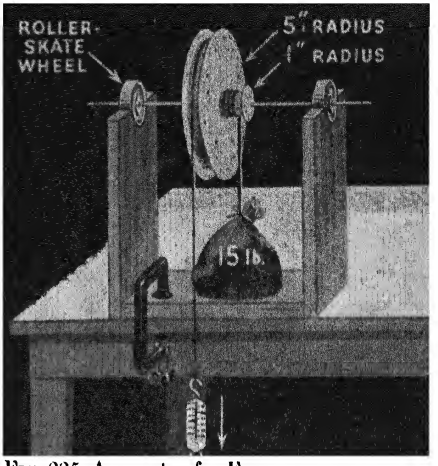


FIG. 225. Apparatus for Experiment 10

In the experiment you found that it took only a little more than three pounds of force to lift the fifteen-pound weight. As the movable part of the machine turned, the force had to travel a distance that was equal to the circumference of the large wheel. At the same time, the weight had to travel a distance that was equal to the circumference of the axle. From the measurements you made in the experiment, you found that the force moved five times as far as the weight moved. Thus, the mechanical advantage was five.

How could you increase the mechanical advantage of a wheel and axle? As in the case of the other machines you have studied, this could be done by making the force move a greater distance in comparison with the distance the weight moves. Remember that the force has to move a distance as great as the circumference of the wheel while the weight is moving a distance equal to the circumference of the axle. With a larger wheel and a smaller axle, the force would have to move through a greater distance while

the weight moved a smaller distance. In this way the wheel and axle would help make work even easier to do.

In Problem 1 you found several examples of the wheel and axle. Some other machines of this kind are hoisting derricks on automobile wreckers, cranks, and the works of clocks and watches. (A crank acts as one spoke of the wheel of a wheel and axle.) When you study power machines in Unit 9, you will discover that almost every one of them is, in part, a wheel-and-axle machine.

Self-Testing Exercises

1. How could you increase the mechanical advantage of a wheel-and-axle machine?

2. Why does a car steer more easily if the steering wheel has a large diameter?

HOW DO SCREWS HELP US DO WORK? You could not possibly lift one end of an automobile with your hands. But you probably have lifted part of the weight of an automobile with a *jack*. You may have seen workmen lift the corner of a house with a large *jackscrew*. How can these small machines lift such heavy objects by the use of only small amounts of force?

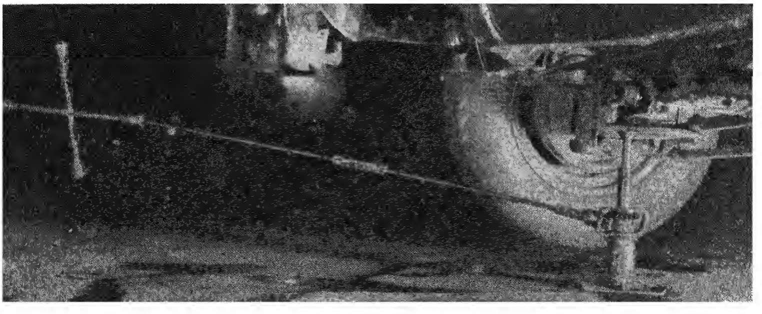


FIG. 226. In this picture of an automobile jack can you find a wheel and axle in the jack? Is any part of the handle a wheel and axle?

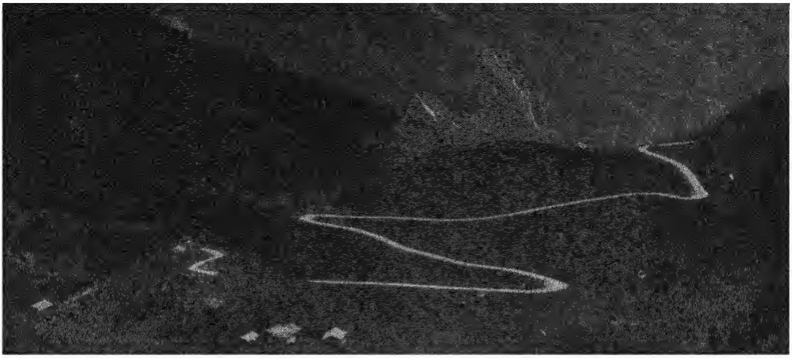


Fig. 227. A mountain road with its so-called *switch-backs* is an inclined plane and a screw. You travel farther to get to the top, but you travel with less effort. (Photo by De Cou from Ewing Galloway)

In each of these devices a screw helps do work. A screw is really nothing but a cylinder with a spiral ridge around it. The spiral ridge is the *thread*. Some threads are V-shaped, and others are rectangular. Examine several kinds of screws to see what the threads are like. A screw is a kind of inclined plane, as you can see from this experiment: Cut a right-angle triangle from lightweight cardboard. Begin at the broad end and wrap it around a pencil. You will have a model of a screw. The screw in a jackscrew fits into a threaded base. The base is heavy and does not move. A long bar or handle is put into an opening in the top of the threaded cylinder. The handle is really a kind of lever. While the handle is turning in a large circle, the cylinder makes a smaller turn. This raises the cylinder a height equal to the distance between the top of one thread and the top of the next one. This distance is known as the *pitch*.

With screws, as with other simple machines, the mechanical advantage is in having the force move a great distance while the weight is lifted a very small distance. The force moves around the circumference of the big circle made by the handle, while the weight is lifted only the small distance of the pitch of the screw. You can

FIG. 228. Do you see any wheel-and-axle machines in this picture? Do you see any screws? (Nesmith and Associates photo)

easily see that the mechanical advantage of this machine is large, for the circumference of the circle made by the handle will be many times greater than the pitch of the screw. How could you increase the mechanical advantage of a jackscrew? One way would be to use a longer handle. Then the force would move through a much greater distance in comparison with the distance the weight was lifted. Another way would be to use a screw having a smaller pitch.

You may have seen a meat grinder, a bookbinder's press, a vise, and other similar machines in use. Each of these machines has a screw for its principal working part. Now when you see such machines being used, you will know why they are of so much help in doing work.

Self-Testing Exercises

1. Which would make a jackscrew easier to operate: (*a*) a handle three feet long, or (*b*) a handle two feet long? Explain your answer.

2. Why is it possible to have such a high mechanical advantage with a jackscrew?

Problems to Solve

1. Explain why you can screw a nut on a bolt very much tighter with a wrench than you can with your fingers.

2. Make a drawing of a vise. Why is it possible to clamp objects so tightly in a vise?

HOW DO WEDGES HELP US DO WORK? Suppose you needed to move a weight so great that you could not roll it up an inclined plane. Instead of trying to pull or roll the weight, you could drive the inclined plane under it. An inclined plane used in this way is called a *wedge*. When a woodsman uses an ax to split wood and a farmer uses a plow to break the soil, they are using wedges. The blades of carpenter's planes, knife blades, and chisels are other examples of wedges.

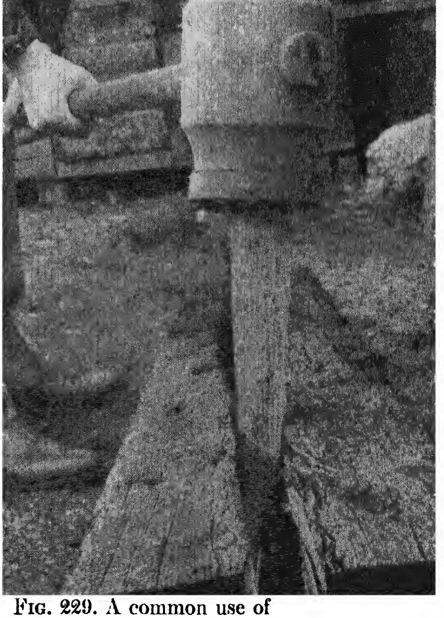


FIG. 229. A common use of the wedge (Starek Studios)

When a woodsman splits a block of wood with a wedge, he must force the wedge in a long distance to separate the wood a little (Figure 229). For example, if the wedge is ten inches long and two inches thick at the top, the wedge has to move ten inches to move the pieces of the block two inches apart. In other words, the force moves five times as far as the parts of the block spread, and the mechanical advantage of this machine is five. What kind of wedge would you need to use to get greater mechanical advantage? If you used a wedge twelve inches long

FIG. 230. You can easily see that a snow plow like this is a wedge and that it is made of two inclined planes.

and two inches thick at the top, the force would move twelve inches while the wood was being forced two inches apart. The mechanical advantage of this wedge would be six. The longer the slope of the wedge and the narrower it is at the top, the greater its mechanical advantage will be. However, you must remember that the friction between the wedge and the material that is being split reduces the advantage.

Self-Testing Exercises

1. A wedge is a very inefficient machine. Explain why.
2. If you want to use a wedge that has a very large mechanical advantage, what kind of wedge should you use?

Problems to Solve

1. Measure the screw of an automobile jack to find its pitch. Would a wider pitch between the threads of the screw make the jack easier or harder to operate? Explain.
2. Suppose you can pull with a force of 100 pounds. How heavy a load could you lift with a single movable pulley? With a single fixed pulley? Why?
3. In a wheel and axle the wheel has a circumference of three feet and the axle has a circumference of six inches. What is the mechanical advantage of the machine? If you could pull with a force of 100 pounds, how heavy a weight could you lift with this machine?

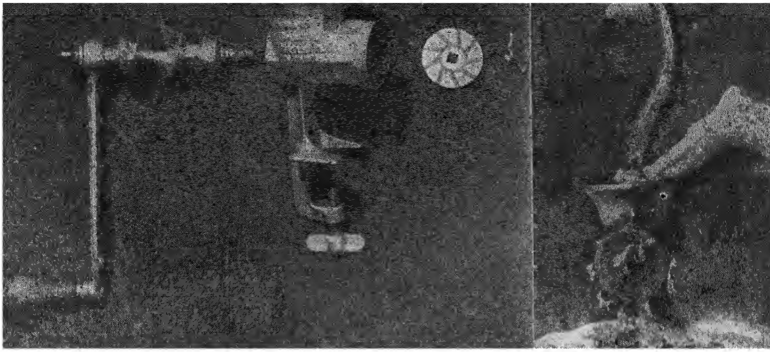


FIG. 231. A food-grinder with its screw, wedges, and wheel and axle

4. A jackscrew has a pitch of one-fourth inch. The handle is three feet long. If the screw is well oiled, about how much could you lift by exerting a force of 50 pounds on the end of the handle?

HOW DO SIMPLE MACHINES WORK TOGETHER IN COMPLEX MACHINES? Many of the machines you use are combinations of simple machines. Take for example the bicycle. As you ride, you push down on the pedals. The pedals and the front sprocket make a wheel and axle. The pedals are pieces of metal that act like spokes of the wheel, and the sprocket is the "axle." The force from the sprocket is transmitted to the rear sprocket by a chain. The rear sprocket and the rear wheel form a second wheel and axle. But in this case the force is applied at the axle, and the resistance is at the rim of the wheel. Thus this wheel and axle at the rear multiplies distance. With a large sprocket driving a small one and the small one turning a wheel with a large circumference, this combination of simple machines produces a great increase of speed and distance between your foot and the ground.

The common food-grinder is another combination of simple machines. The crank is one spoke of the wheel of a wheel and axle. On the axle is a screw. Food is caught in this screw and pushed forward against the cutting edges at the outer end. These cutting edges are wedges. Thus

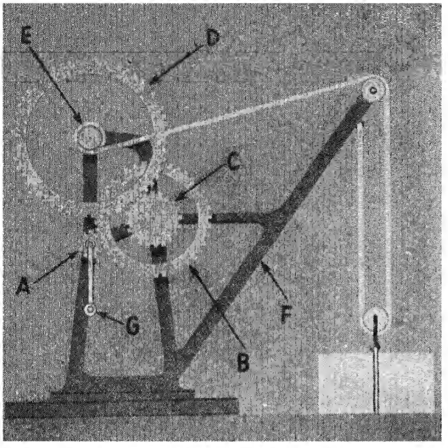


FIG. 232. Be sure that you can explain how this machine works. The spokes of wheels B and D are left out of the drawing to make it clearer.

the food-chopper is a combination of a wheel and axle, a screw, and wedges. Several additional screws are used to fasten the machine together and to clamp it to a table.

The crane shown in Figure 232 is also a combination of machines. The force is applied at G. You see that gear wheel A, to which the crank is attached, is very small. This gear drives gear B, which is much larger. Gear B has axle C attached to it, which is much smaller. Gear C drives gear D, which is much larger. Gear D is attached to axle E, which is much smaller. Around axle E is a rope that connects with a single movable pulley. By arranging several wheels and axles with pulleys in this way, handle G can turn around more than twelve times while axle E turns only once and lifts the stone perhaps six inches. Sometimes the beam (F) is used as a lever. It is attached at the lower end so that it can swing up or down, and is moved by a different set of wheels and axles. So you can see that a crane may be a combination of several wheels and axles, pulleys, and levers.

If you have at home a sewing machine that you operate by pressing on a treadle, you will find that it is a combination of many simple machines (Figure 233). You apply force to the treadle, which is a lever. A rod transmits the force to a crank that is part of a wheel and axle. By means of a belt, the large wheel drives a small wheel at high speed to operate the parts of the sewing machine.

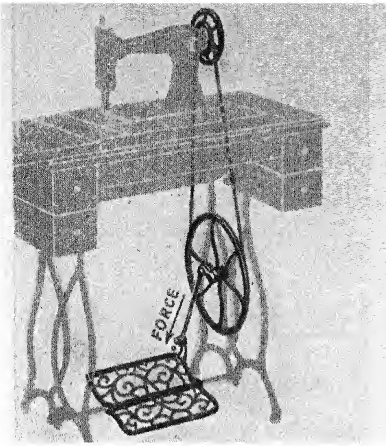


FIG. 233. Some of the machines in a sewing machine

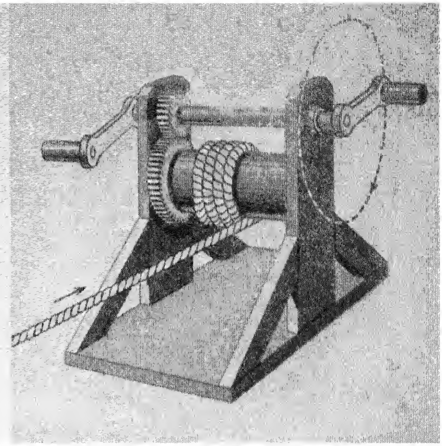


FIG. 234. How a windlass multiplies force

These parts consist of many wheel and axles and levers. The needle that does the sewing is a wedge. All of these simple machines operating together increase the speed of the machine and change the direction of your force to make the needle move through the cloth at a rapid rate of speed.

When properly arranged, each simple machine in a series multiplies the mechanical advantage. In the windlass (Figure 234) suppose that one wheel and axle (the crank and its gear) has a mechanical advantage of twelve, and the other has a mechanical advantage af six. The total mechanical advantage of the windlass will be 12 x 6, or 72. One pound of force on the crank will lift almost 72 pounds on the rope.

An easy way to find the mechanical advantage of a complicated machine that multiplies force is to use the general principle for simple machines. Move the part where the force is applied a distance of, perhaps, three feet. Then measure the distance the working part has moved. Divide the first distance by the second to get the mechanical advantage. Thus, if the force has moved

three feet and the working part has moved one-half inch, the mechanical advantage of the machine is 72 (36 inches divided by .5 inch).

Self-Testing Exercises

1. What is the advantage of using a combination of simple machines?
2. How can you find the mechanical advantage of a complicated machine?

Problems to Solve

1. Suppose that the front sprocket wheel of a bicycle is eight inches in diameter, and the rear sprocket wheel is two inches in diameter. Suppose, also, that the rear wheel is twenty-eight inches in diameter. How far does the bicycle go while the pedal makes one complete revolution? (You might figure this out, using the dimensions on your own bicycle.)
2. Find out what is meant by a "high-gear bicycle" or a "low-gear bicycle."
3. Suppose that you live in a place where it is rather hilly. The dealer shows you two bicycles. On one bicycle the back wheel goes around five times while the pedals go around once. On the other, the back wheel goes around three and one-half times while the pedals go around once. Which bicycle would you rather have? Why?
4. Examine as many of the following machines as you can to find what kind of simple machine is the basis of operation of each: clothes wringer, washing-machine, broom, ice-cream freezer, grindstone, sugar tongs, shovel, can opener, door knob, key, braking system on an automobile. Examine other machines that are not mentioned in this list. You may find that some of the complicated machines are made of several kinds of simple machines.
5. Find out how the brakes on an automobile work. (If possible, use the handbook that comes with the car.) Figure out, if you can, the mechanical advantage of the brake mechanism.

FIG. 235. This little chap knows how to reduce the friction in his roller-skates so that he can skate with less effort.

Problem 4:
HOW DO WE CONTROL FRICTION IN OUR MACHINES?

HOW CAN FRICTION BE REDUCED? In Problem 2 you learned that a machine can never give out 100 per cent of the work that is put into it. You learned also that the work which is lost in a machine is lost because of friction between its moving parts. Therefore you can see that it is important to have machines work with as little friction as possible if we are to get the most work out of them. A simple experiment will help you realize how much the friction in a machine can be reduced.

EXPERIMENT 11. *How Much Do Rollers Reduce Friction?* (*a*) Get a chalk box or a cigar box and some metal or wooden rollers. Round pencils will do very well. Put weights or sand in your box until it weighs several pounds. Fasten a spring balance to one end of the box and slide it along the top of a table at a uniform rate of speed. How much force is needed to pull the box?

b) Now put rollers under the box and pull the load along the top of the table at a uniform rate of speed. How much force is needed to pull the box when it is on rollers?

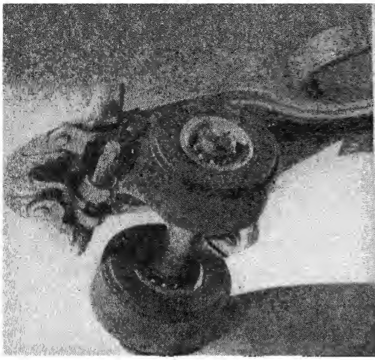


FIG. 236. You can see the ball bearings in these wheels.

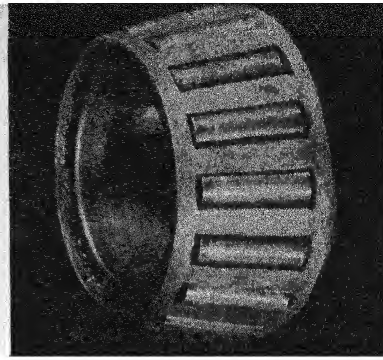


FIG. 237. The rollers of a large roller bearing (Starek Studios)

In the experiment you have just done, you found that it took much more force to slide the box along the table-top than it did to move the load on rollers. In any machine there are always moving parts that are in contact with each other. These parts can never be perfectly smooth. The little ridges and depressions on one part move against uneven places in the other part and cause friction. When surfaces slide past each other in this way, there is *sliding friction* between them. The bottom of the chalk box resting on the table top caused sliding friction that had to be overcome before you could move the load. In part *b* of the experiment you put rollers between the surfaces. As the box and rollers moved along, the tiny ridges and depressions that cause friction were lifted out of each other instead of being pulled against each other. Thus it was much easier for the box to move along.

But there was still some friction. This friction between a roller or a wheel and a surface is called *rolling friction*. It is usually much less than sliding friction. Examine a roller-skate wheel carefully to see how it is made. Small steel balls roll around the skate axles. These sets of steel balls are known as *ball bearings* (Figure 236). In many kinds of machines they substitute rolling friction for sliding friction between the wheels and the axles.

Figure 237 shows a kind of bearing that is used in heavier machinery. It looks like a set of tiny rollers in a larger wheel, and that is just what it is. It is a *roller bearing*. The axle of a heavy piece of machinery rests inside the rollers. As the axle turns, it turns the rollers around inside the bearing. Thus the rollers make the friction much less. Roller bearings, used on the axles of the best trains today, make it possible for the locomotives to pull heavier loads and increase our comfort as we ride. So one way of reducing friction between moving surfaces is to use steel balls or rollers instead of allowing the surfaces to rub against each other.

We can reduce friction in another way. Rub two pieces of very rough wood against each other and notice how hard they are to move. Sandpaper each piece of wood until it is as smooth as you can get it. Rub the pieces together again, and you will find that they are much easier to move. Do you see that another way of reducing friction between moving surfaces is to make the surfaces as smooth as possible?

Take the back off a good watch and find the place where the axles of the wheels turn. Be careful not to touch the works or to get any dust inside. Jewelers have learned that they can make watches keep better time if they reduce friction between the moving parts. Therefore the ends of each main axle are set in hard minerals known as *jewels*. These hard substances are made very smooth, of course, so that the delicate mainspring can turn the wheels easily. Can you see why *jeweled bearings* make a watch more expensive? The next time you hear someone say that he has a twenty-one-jewel watch, you will know why the watch has jewels in it.

There is still another kind of bearing used where parts

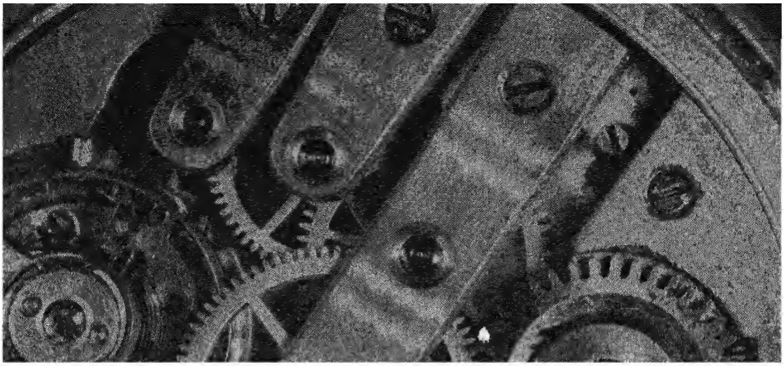


Fig. 238. In this picture you can see at least four jeweled bearings. What simple machines can you see? (Starek Studios)

of machines rub against each other. If the axles of a machine and the bearings into which they fit were made of the same kind of metal, the machine would not run very easily. The tiny ridges and depressions in the axle would fit into the ridges and depressions in the bearings, and much friction would be produced. To reduce friction and wear where ball or roller bearings cannot be used, steel axles turn in bearings that are lined with a kind of soft metal known as *Babbitt metal.*

Did you ever ride in an automobile that squeaked? The squeaking noise grew very tiresome, and either you or your father probably said, "This car should be greased." When we grease or oil parts of machines that rub against other parts, a thin film of oil spreads out over the parts and keeps them from actually touching each other. The oil lets one part slide over the other more easily, and friction is reduced. So a fourth way of reducing friction is by using oil or grease to keep the movable parts of a machine separated.

Of course, the proper kinds of oil must be selected for different purposes. The crank-case of a car needs *cylinder oil,* the gears need a pasty kind of grease, and the springs need an oil and *graphite* mixture. Graphite is a form of carbon that is very "slick." Small machines need a thin,

light oil, commonly known as *machine oil*, and different kinds of oil are even used in automobiles in different kinds of weather.

HOW IS FRICTION USEFUL TO US? Can you imagine a world without friction? Probably the nearest to that kind of world occurs during an ice storm. Roadways, walks, and steps are covered with a thick coating of the smoothest ice. The first people out do not realize how little friction there is. They go down one after another. Many bones are broken, and almost everyone who goes out falls sooner or later. Anyone who tries to run can hardly get started. Autos turning corners go whirling round and round. When they get on the side of a sloping street or road, they cannot get back to the middle again. A person can hardly get up a slope on foot until he has spiked soles, and automobiles need tire chains to press into the ice and increase the friction.

The strange and often dangerous things that happen when everything is coated with ice are caused by gravity and inertia acting with little friction. With no friction at all, gravity would pull all loose things down slopes into the low places. If you got started moving on a level space, you could not stop until you bumped squarely into something. Then you would probably bounce off and start sliding in another direction. If you were stopped, you could get started only by pushing against some other object.

Of course, we shall never see a world without friction. The only frictionless place we know about is out in space where the earth and other heavenly bodies have been spinning ever since they were started. In empty space there is no friction to stop them. But here on earth we both have and want friction. In fact, we often go to a great deal of trouble to increase friction between things.

FIG. 239. On a slick gymnasium floor we wear rubber-soled shoes, usually with ridges on the soles, to increase the friction between the floor and shoes. (Starek Studios)

When you strike a match, you choose a place that is rough, so that there will be greater friction. You have seen a speeding automobile come unexpectedly to a red light. The driver put on the brakes, and the machine soon came to a stop. The brakes are lined with a tough substance that causes much friction when pressed tightly against the *brake drums* on the wheels. The surfaces of the *brake linings* hold back on the surfaces of the drums and thus stop the wheels. At the same time the rubber tires with their ridges and grooves (the *tread*) "grip" the road with much friction and do their part in stopping the car.

You can now understand that there are many places where friction in our machines must be controlled. Friction always changes mechanical energy into heat energy. This energy is lost. In the bearings and other rubbing surfaces of machines we are careful to have as little friction as possible. Thus our work is done with less wasted energy, and the surfaces are kept cool and do not wear our rapidly. But brakes, tires, and other parts must have as much friction as possible. Thus they can change motion into heat and stop our machines when that is necessary.

All important machines are carefully inspected before use to make sure that the friction-controlling devices are in order. Mechanics go carefully over every locomotive, airplane engine, and racing car. They put oil on bearings, and they see that there is fresh oil in all the reservoirs with no leaks in the oil pipes. They inspect the bearings to see that there are no worn or loose-fitting Babbitt metal linings and no broken rollers or balls where rolling friction is used. The brake linings must be in good condition and correctly adjusted. The sand box of the locomotive must be full so that the engineer can "sand the track" for quick stops. The tires of automobiles must have good treads.

If we are wise, we will check our own machines just as carefully, or see that they are inspected by experts. Then they will do their work well and last longer. In the case of our automobiles, we ourselves may live much longer because we are able to use friction effectively when we need it.

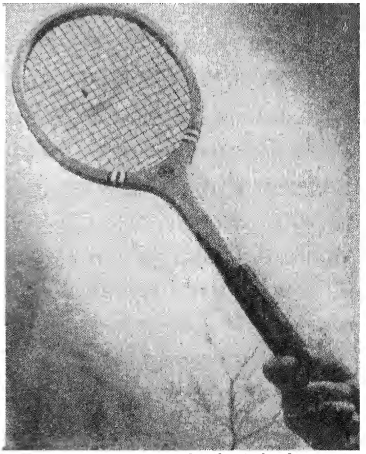


FIG. 240. We wind *friction tape* around the handles of baseball bats, tennis rackets, and hockey sticks to make them easier to hold. (Starek Studios)

Self-Testing Exercises

1. Make a list of ways in which friction helps. In what ways is it a disadvantage?

2. How can we reduce friction? If possible, give examples different from those used in the text to illustrate your explanations.

3. Why do we often substitute rolling friction for sliding friction? Give a reason for the difference.

Problems to Solve

1. Why are different kinds of oils used in different kinds of machines? Talk with "oil men" and read manuals that tell how to take care of machines.

2. What is the *coefficient of friction?* A physics book will probably give you the answer. Can you calculate the coefficients of friction in parts *a* and *b* of Experiment 11?

LOOKING BACK AT UNIT 4

1. Copy the heading of each sub-problem of this unit. Try to answer each of these questions as briefly as possible and in your own words. The first sub-problem is on page 205: *What kinds of work does man do with machines?*

2. Show that you understand the meaning of these words:

mechanical advantage	*fulcrum*	*work*
block and tackle	*machine*	*jewel (watch)*
pitch (of a screw)	*foot-pound*	*roller bearing*
lever	*jackscrew*	*friction*

ADDITIONAL EXERCISES

1. Get the members of your class to bring to school many different kinds of simple machines. Prepare an exhibit of these machines. Put a label on each machine, telling its class, how it works, its mechanical advantage (if possible), and other important items you may wish to add.

2. See how many simple machines you can find in a kitchen. Make a list of levers, wedges, etc., that you find.

3. Try to analyze some complicated machine, such as a bicycle or a sewing-machine, to find the simple machines used in them. Make a table showing the kinds of simple machines and the number you find in each complicated machine.

4. Try to rig up a block-and-tackle system of pulleys that has six supporting cords. Make a diagram if you cannot get the pulleys. What is the mechanical advantage of your system?

5. How would the amount of work done in carrying a fifty-

FIG. 241. This farmer certainly knows how to use machines. Why did he use the plank under the chain?

pound box ten feet along a level floor compare with the amount of work done in carrying the same box up a ten-foot stairway?

6. Suppose a 160-pound man is painting the side of a house. He sits on a plank supported by a set of pulleys at either end. The plank weighs 25 pounds. How much work does he do if he pulls on the rope supporting the pulleys and raises himself and the plank 25 feet?

7. Visit an automobile repair shop or machine shop to learn what use is made of simple machines. In a repair shop you can see many of the inner parts of automobiles. Be sure to get permission to look around the shop. Be careful not to get in the way of the mechanics, and do not handle things that should not be handled.

8. Make a list of the parts of different machines that use inertia. For example, each sewing-machine has a heavy wheel to keep it running smoothly, and typewriter type strikes the paper after a quick stroke.

9. *Centrifugal force* is a form of inertia, but it is an interesting study in itself. Read all you can find about it, beginning with pages 234-235 of *Science Problems, Book 2*. Then see how many machines you can find that use it. (You use it in a spring window-shade roller each time you raise the shade. How?)

10. Make a list of the devices that use springs to store energy. For example, a spring in a door lock stores energy to push the bolt out again when you release it.

11. How does a hydraulic press work? An encyclopedia or a physics book will tell you.

12. Find examples of devices that use the principle of the hydraulic press. To begin with, you might look at a barber's chair or a hydraulic jack in a garage.

13. Study the mechanical brake system in a car. Make a diagram to show the different simple devices used.

14. Find how the hydraulic brake system on an automobile works.

15. Read in a reference book about *differential pulleys* to learn what they are and how they work. Then look for differential pulleys in garages and machine shops.

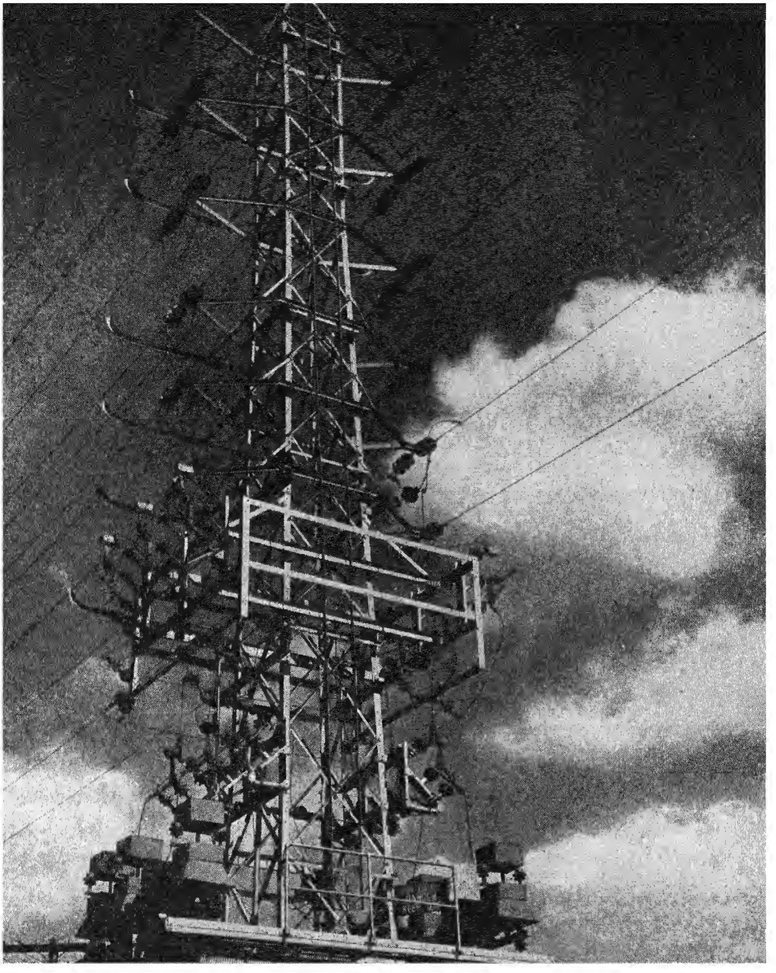


FIG. 242. Through millions of miles of wire, that spread like a network over almost all of our country, flows that silent, invisible, and powerful energy that we call electricity. It lights our buildings, makes heat for us, and runs our machinery. How do we produce this form of energy? What must we know about it in order to use it? The unit you are now to study will help you answer these questions. (Nesmith and Associates photo)

UNIT FIVE

UNIT 5

HOW DO WE MAKE ELECTRICAL CURRENTS?

INTRODUCTORY EXERCISES

1. Make as long a list as you can of the uses of electricity. Mark with a star each way that you yourself have used electricity.

2. What is meant by the term *positive charge of electricity?*

*3. How could you use an electrical current to make a magnet?

*4. What is meant by the *field of force* of a magnet? How could you show the field to someone who did not know about it?

5. What would you need to make a simple electrical cell, that is, one that would make electrical current by chemical action? How would you arrange the parts so that the cell would work?

6. Make a diagram to show how you would connect your cell to light a small light-bulb.

7. What is meant by the *voltage* of an electric cell or generator?

8. Explain how a simple electric generator makes electrical current.

9. Where do we get the energy with which to make the great quantities of electrical current that are used in this country?

10. How does a storage battery work?

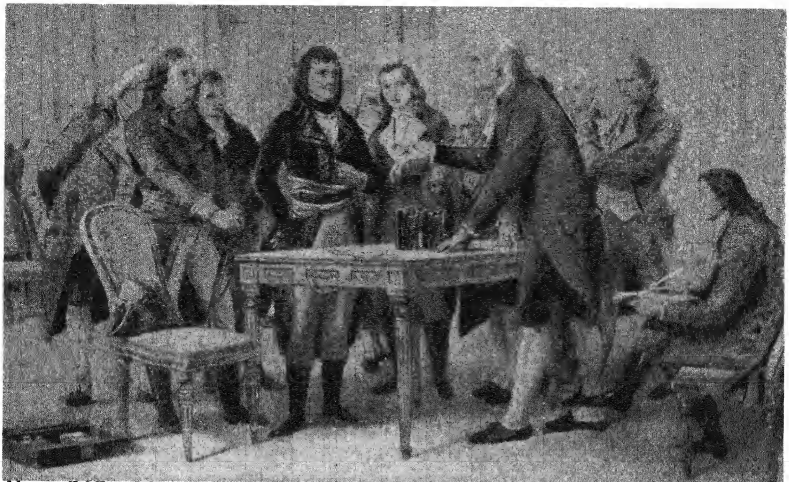


FIG. 243. Alessandro Volta explains his electric cell to Napoleon Bonaparte. Volta's cell was of greater importance to the world than all of Napoleon's military victories.

LOOKING AHEAD TO UNIT 5

HOW MANY times have you used electrical current in the last few days? If you live within reach of a great network of electric power lines, you have most certainly used it many times—for light, to toast your bread, to help you sweep, to keep your food cool, to run toys, to ring door-bells, and to operate radios. If you do not have electric wires coming to your house, you may have your own electric power-plant run by a gasoline engine.

Even if you do not have electrical current for general use, you may use electricity more often than you think. Every flashlight, every telephone, and every automobile uses electrical current. Electricity prints your daily or weekly newspaper. Electricity formed the plates from which this book was printed, and electricity plated the chromium and the silver on many of the things you use every day. Electricity carries telegrams, guides our air-planes, runs our street-cars, and lights our streets. How differently most of us would live if scientists had not learned how to make electrical currents!

FIG. 244. Michael Faraday explains to his wife the discovery that made possible the electric motor. A metal bar floating on mercury whirled around a wire when electrical current passed through the wire.

People have not used electrical current very long. Less than 140 years ago Alessandro Volta, an Italian scientist, discovered the first practical way to make an electric current. Volta discovered how to change chemical energy into electrical energy. His invention was the ancestor of our modern electric "battery," or cell. It was used at first by scientists to carry on experiments. Of course, it produced only a very small amount of electricity—so small, indeed, that 2000 of these cells were needed for some of the experiments the scientists were doing. You can easily see that such a cell had to be greatly improved or some other way of making electricity had to be invented before we could use electricity as we do today. The practical use of electricity in our homes would never have developed far if it had not been for a great discovery by the British scientist Michael Faraday. About 110 years ago Faraday found a way to change the energy of a moving machine, such as a steam engine, into an electrical current.

Since the time of Faraday, that is, in the last 100 years, almost all the great inventions and developments in the use of electrical current have been made. Your grandfather and grandmother saw the development of electric lights and telephones. Your father and mother

can remember when there were no radios. You, yourself, will probably see other important electrical devices come into use.

Of course, you want to understand all you can about how electricity works. Some devices, like the radio, are so complicated that you would need to do a great deal of special studying to learn how they work. But many devices are simple and not nearly so mysterious as you often think. In this unit you will learn something of how electricity acts and the important ways of making electric current. You probably know already how the current is used to make electromagnets, to light lamps, and to heat toasters. In Unit 8 you will learn how electrical currents are used to operate such devices as motors, telephones, telegraphs, and radios.

Problem 1:

HOW DO ELECTRICAL CHARGES BEHAVE?

ONE WINTER morning Jack Thompson was combing his hair vigorously. But the more he combed, the more his hair stood on end. It actually seemed to be trying to stick to the comb, and the comb made queer crackling sounds. If he had stood before a mirror in a dark closet, he could have seen tiny sparks around the teeth of the comb. When Jack laid the comb down, some scraps of paper on the table flew at the comb as if they were alive. Finally he got his hair to behave by wetting it thoroughly. However, when he brushed his coat, the white pieces of lint that he brushed off seemed to fly right back on the coat. When he finally got ready to start to school, he rushed for the front door. As he reached for the door knob, there was a sharp "crack," and a needle seemed to stick his finger.

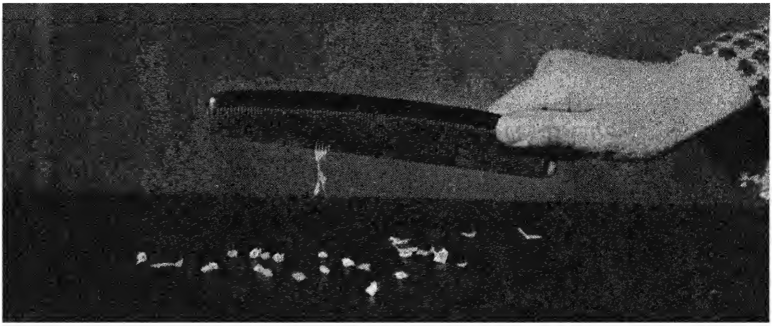


Fig. 245. The simplest way of seeing what electrical charges will do

Jack was in too much of a hurry to think about the queer things that were happening to him. However, when he went to his science class, his teacher, Mr. Crane, said that it was a good day to study *static electricity*. Most of the students did not know what static electricity was, even though they had heard "static" on the radio. So they began asking questions, but Mr. Crane told them that they could find out for themselves. He started them off on some experiments, and they did answer some of the questions. Yet, when they got through, they had more new questions than answers.

HOW DOES STATIC, OR FRICTIONAL, ELECTRICITY ACT? People knew about static electricity thousands of years before the time of Volta and Faraday. The ancient Greeks noticed that amber would attract little pieces of straw and thread after it had been rubbed, just as a rubbed comb attracts bits of paper. (Amber is yellowish-brown gum, or tree sap, that has hardened into a stone-like material. It is used to make beads and other ornaments.) The Greek name for amber was "elektron"; so things that acted like amber were said to be *electric*. We now say that they have an *electric charge* or that they are *charged with electricity*.

EXPERIMENT 12. *How Do Frictional Charges Make Things Act?* (*a*) Rub a hard-rubber comb vigorously on a woolen coat sleeve or run it through your dry hair. Bring the teeth of the

FIG. 246. Apparatus for part *b* of Experiment 12

comb slowly down toward some very small, dry paper wads on the table. What does the paper do? Why? (This experiment may work better if the paper wads are laid on a clean piece of window glass.)

b) Fasten a small dry paper wad (or a ball of pith) on the end of a piece of silk thread about one foot long. Fasten the other end of the thread on some support so that the paper hangs free in the air. Rub the comb on woolen cloth again and bring the teeth to the paper. What does the paper do after a moment?

c) Rub a glass rod or a piece of glass tubing with a silk cloth. Then bring the glass near the paper that has touched the comb. What does the paper do at first? What does it do after it has rubbed along the glass for a few moments? If it flies away from the glass, try the comb again. Carefully write down just what happened in each case. Then write down the questions you want answered.

Electric charges produced by rubbing one material on another, as you have done, are generally known as *frictional* electricity or *static* electricity. Of course, the name "frictional" was given because of the rubbing that

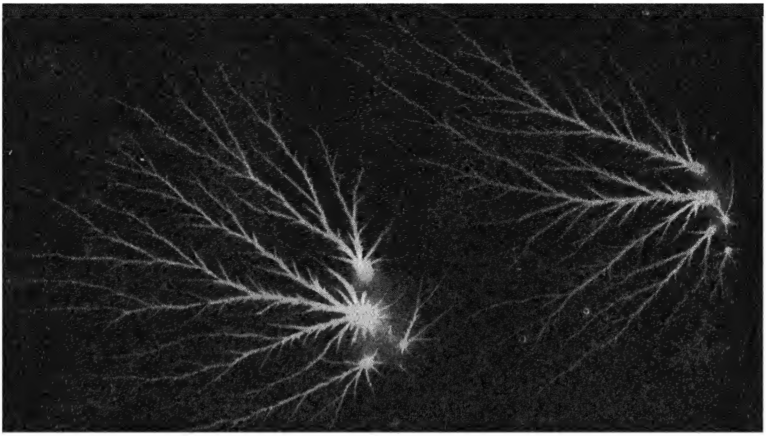


FIG. 247. Frances M. Davis, X-ray artist of Santa Monica, California, explains how she took this picture: "One day when I was full of static and in a hurry, I touched this film in the dark, and this pattern developed where sparks had jumped from my fingers."

was necessary to produce the electric charge. The word "static" means "at rest" or "standing still." Scientists used to believe that charges of electricity produced by friction did not move. For this reason they gave them the name static electricity.

In your experiments you probably found that a paper wad was at first attracted to the charged comb. In a moment or so after it had touched the comb, it flew away again and then moved around in all sorts of queer ways as if it were afraid of the comb. Yet, when you rubbed a glass rod with silk and brought it near the paper that was "afraid" of the comb, the paper moved toward the glass. After it had rubbed along the glass for a moment, the paper wad flew away from the glass and then seemed to be "afraid" of it. But, after flying away from the glass, it was attracted by the comb again.

Pieces of paper do not usually act in such queer ways. The invisible electric charges must have caused this strange behavior. How can we explain it? Sometimes the paper wad is attracted to the comb, and sometimes it flies away. When it flies away from the comb, it tries to touch the charged glass rod. There must be two kinds of electric charges, one kind on the comb and the other on the glass. Scientists came to this same conclusion after doing experiments like yours and many others. They said that the charge on a glass rod rubbed with silk was a *positive* charge. The charge that resulted on a rubber comb that was rubbed with hair or with wool was a *negative* charge.

Can you tell from your experiments how two charges of electricity act toward each other? When the paper wad touched the comb, it received a part of the electric charge from the comb. Both were charged with negative electricity. Then the paper moved away, or was repelled. Next, you brought to the paper an object that was positively charged. What did the negative charge on the paper do? It tried to get as near the positive charge as possible. But in just a moment the paper had taken part of the positive charge from the glass. Then it flew away from the glass.

From the way these charged materials acted, you can see the reasons for the rules that scientists have made to describe how electric charges act. They say that *two different charges always attract each other*. When the paper had a negative charge, the positive charge on the glass attracted it. When it had a positive charge, the negative charge on the comb attracted it. Scientists also say that *two like charges always repel each other*. When the paper had received part of the negative charge of

the comb, it was pushed away, or repelled, by the charge on the comb. These two simple rules seem always to hold true. In thinking about how electricity acts, you will find it very helpful to remember that different charges attract each other and like charges repel each other.

Self-Testing Exercises

1. How did electricity get its name?

2. Write down the two rules that tell how two charges of electricity act toward each other. Give an illustration of each rule. If you can, use an illustration that is different from those in the book.

3. Do the charges on two combs pull the combs toward each other or push them apart? How do you know? Plan a way to test your answer. If possible, try out your plan.

4. Make up an experiment to show how a charged comb and a charged glass rod behave toward each other. Try out your experiment.

WHAT IS ELECTRICITY? Many people would be greatly puzzled if you asked them to tell you just what electricity is. Have you wondered about it? You could not see that your comb was any different after you rubbed it than it was before. Yet it would attract pieces of paper. And in an instant after it had touched the comb, some invisible change had taken place in the paper, and the paper was repelled. You know, too, that electricity is carried through wires for long distances. A wire that is carrying electricity seems no different from any other wire. It looks just the same. It makes no strange sounds. Yet, if you touch a wire that is carrying an electric charge, you may be severely shocked or killed. What is this strange force called electricity?

For a long, long time scientists were just as badly puzzled as you may be. Then, within the last fifty years

many of their experiments and discoveries began to fit together, and they came to have a rather clear idea of what this invisible force is. You remember that all materials are made of molecules and that molecules are made of atoms. Scientists have discovered that all atoms seem to be made of two kinds of electricity—positive electricity and negative electricity. Every atom of every substance contains both kinds. In every atom the positive and the negative charges just balance each other; so the atom is *neutral*, or uncharged. Scientists have further discovered that the negative electricity exists in the form of tiny particles called *electrons*. These electrons are able to move about quite easily. They can leave one material and go to another or move easily through some materials.

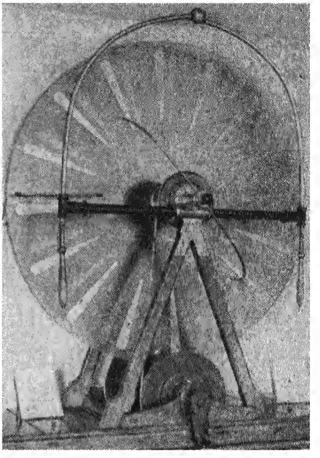


FIG. 248. This huge static electricity machine, made about fifty years ago, has two glass plates each seven feet in diameter, with strips of tinfoil on them. When the plates are whirled rapidly, the machine sends out a fourteen-inch stream of electrical sparks. (Museum of Science and Industry, Chicago)

Every atom of a material also contains one or more particles that have a positive charge. The positive particles are called *protons*. Protons are nearly 2000 times as heavy as electrons. Unlike electrons, they cannot move easily. In all solid substances they seem to stay in their places. In every atom there is usually an equal number of electrons and protons; therefore the atom is neutral.

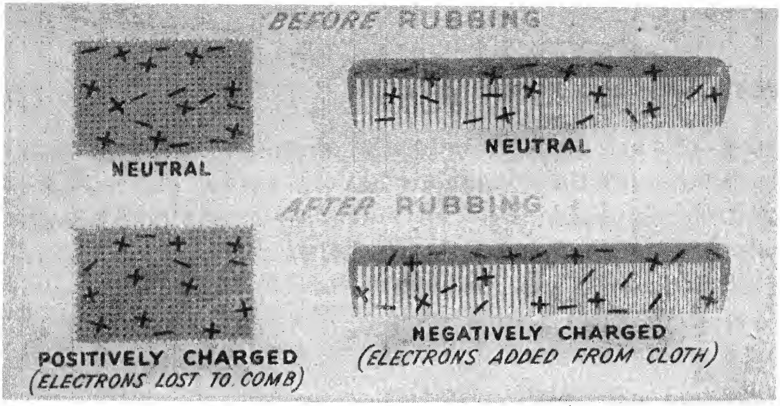


FIG. 249. Be sure that you can explain this diagram, which shows what happened in part *a*, Experiment 12.

Now let us see if we can explain what happened in your experiments. First, how did the materials become charged? To start with, your rubber comb was neutral. It had the same number of positive and negative particles in it. When you rubbed it on the woolen cloth, it became negatively charged. Now how did this happen? To have a negative charge, it must have gotten some electrons from somewhere. And that is what happened. It took away some electrons from the woolen cloth. Now it was no longer neutral because it had more electrons than were needed to balance the protons in it. It therefore had a negative charge.

If you had a way to test the woolen cloth, do you think that it would show a positive charge or a negative charge? The woolen cloth would show a positive charge because it had lost some of its electrons. Rubbing a glass rod with silk moves electrons from the glass to the silk. The silk gets a negative charge, and the glass then is left as positive. Now you see how we explain the charging of hard rubber and glass.

But how was the paper attracted to the charged comb? To explain this, you will have to use the principle that

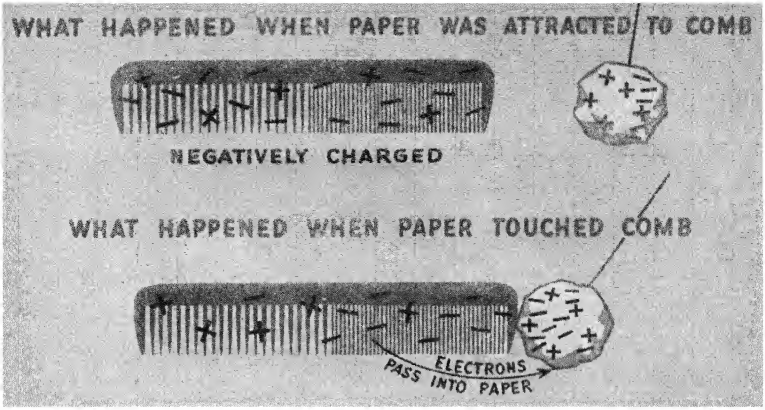


FIG. 250. This drawing shows what happened in part *b*, Experiment 12. Be sure that you can explain it.

like charges repel and unlike charges attract. When the comb (negatively charged) was brought near the piece of paper, the electrons in the paper were repelled to the opposite side of the paper (Figure 250). There was then an attraction between the negative charge on the comb and the positive charge on the side of the paper nearest the comb. The attraction was so great that it overcame the weight of the paper, and the paper dashed up to the comb.

Next, you noticed that the paper was repelled after it was in contact with the comb for a moment. The electrons on the comb were pushing each other apart. Some of them were pushed over on the paper. Then the paper also had more electrons than protons; therefore it was negatively charged and was repelled from the comb.

Self-Testing Exercises

1. If all materials contain charges of positive and negative electricity, why do they not always show an electrical charge?
2. What change must take place in a body to give it a negative charge? A positive charge?
3. Explain why a piece of paper is at first attracted toward a charged comb and then repelled.

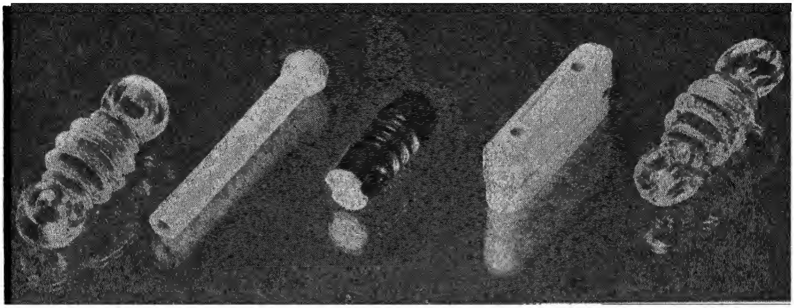


FIG. 251. Porcelain and glass are the common materials used for electrical insulators.

HOW DOES ELECTRICITY MOVE? You are now ready to learn another important fact about how electric charges act. Use a comb as you did in Experiment 12.

EXPERIMENT 13. *How Does Static Electricity Escape from Charged Bodies?* (*a*) Charge a comb by rubbing it with a dry woolen cloth. Pick up some scraps of paper to make sure that the comb has a charge. When you are sure it is charged, rub your hand all over the comb. Again try to pick up the scraps of paper. Is the comb still charged?

b) Charge the comb in the usual way and rub all the charged part on some metal, like a piece of wire. Be sure to pass it between the teeth of the comb. Is the comb still charged?

This experiment shows that the electric charge on a comb disappears when it is rubbed on your hand or on a piece of metal. Scientists have found out by these and other tests that electrical charges cannot move easily through such things as glass, dry air, rubber, resin, and the materials most pens and combs are made of. But charges can move easily through moist air, the human body, metals, and carbon. These materials through which electric charges can pass easily are called electrical *conductors*. Silver and copper are our best conductors.

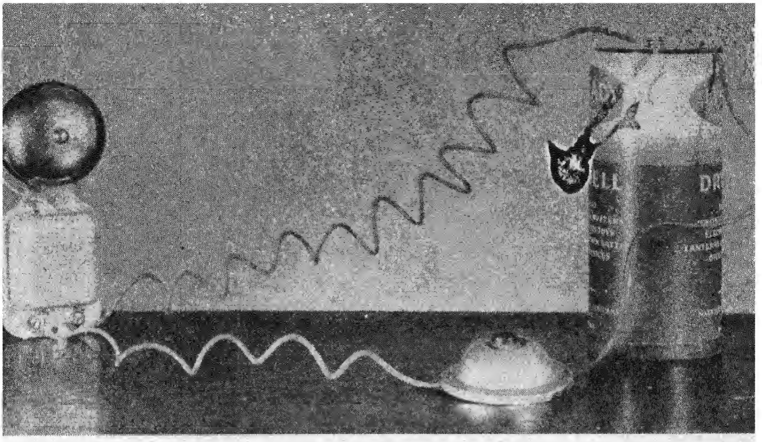


FIG. 257. Apparatus for Experiment 15

his father. "You hustle right up there and pull it out." When Tom had pulled the wire out, they screwed in still another fuse, and the lights were all right. Then Tom's father explained to him about the fuses, switches, and wires in the house. Here are some of the things Tom learned.

HOW DO WE CONTROL ELECTRICAL CURRENTS? To use electrical current in ways that are helpful to us, we must make the current flow, guide it, and start and stop it whenever we want to do so. We do these things when we make an electric bell ring.

EXPERIMENT 15. *How Do We Control Electrical Current to Ring a Bell?* Connect a dry cell to a push-button or switch and to a bell (or buzzer) with insulated copper wire, so that the wire forms a path, or *circuit*, for the electrons to go from the cell through the bell and back to the cell again (Figure 257). You may put the push-button or switch either in the wire that goes from the cell to the bell or in the wire that carries the electrons back to the cell. Push the button or close the switch so that electrons can go all around the circuit. Does the bell ring? Explain the use of each part in controlling the electric current. What advantages has an electric bell over other kinds of bells?

The use of an electric current to ring the bell in this experiment shows you the important parts of any electrical *circuit.* The dry cell takes electrons from the center, or positive, binding post and pushes them out through the other, or negative, binding post. The copper wire is a good conductor; it allows the electrons to pass through it easily. Notice that there is one path to take the electrons to the bell and another to bring them back to the cell. This arrangement is necessary to form a complete circuit. Around the copper wire is cotton, silk, rubber, or enamel, so that the electrons cannot get out of the wire without going where we want them to. The bell uses the current of electrons to operate a magnet that moves the clapper back and forth. The push-button, or switch, lets the electrons through when we want to ring the bell and makes a gap to stop the electrons when we do not want the bell to ring.

Every simple electrical circuit has these four parts: (1) something to make the electrons flow, (2) a good conductor arranged in a complete path for the electrons, (3) one or more devices to start, stop, or regulate the current, and (4) something to use the current.

Let us see how electrical circuits in modern houses provide these four parts. The current is brought to each house by at least two wires that come from a machine called a *generator*. The generator makes the electrons flow by taking electrons out of one wire and forcing them into the other wire. The generator is in a "powerhouse," where it can be run by an engine or by a water-wheel.

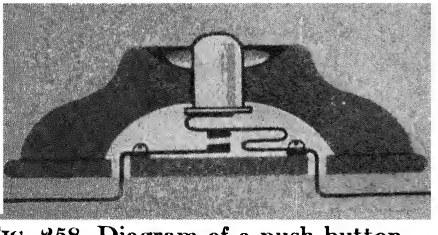


FIG. 258. Diagram of a push-button

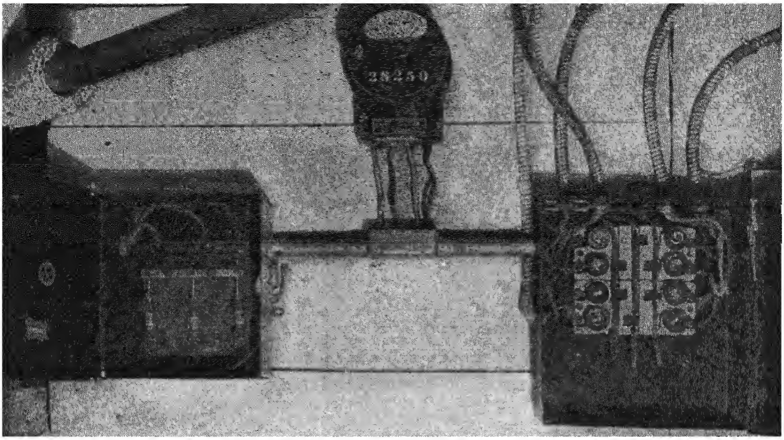


FIG. 259. At the left is the metal switch box. In the center is the meter. At the right is the fuse box with the armored cable leading off to the various circuits of the house. (Claude J. Dyer photo)

Where the wires come into the house is a large switch to turn the current into the wires in the house or to shut it off. This switch is protected by a steel box, so that it will not be touched by accident. In the same box or in another one near by are fuses, or automatic *circuit breakers.*

The fuse works the way it does because of an interesting characteristic of electrical currents. Every electrical current meets some *electrical friction*, or *resistance*, as it passes through its conductor. You know that when two objects are rubbed together, the mechanical friction produces heat. Electrical friction, or resistance, also produces heat. And the larger the current, the greater is the amount of heat. In fact, when we send twice as much current through the wire, the wire gives out four times as much heat.

Now you are ready to understand what a fuse is for and how it works. If the wires in a house carry only as much electric current as they should, they give out heat to their surroundings as fast as it is formed. They do not become hot. However, if we connect too many devices with the wires, so much current will flow that the

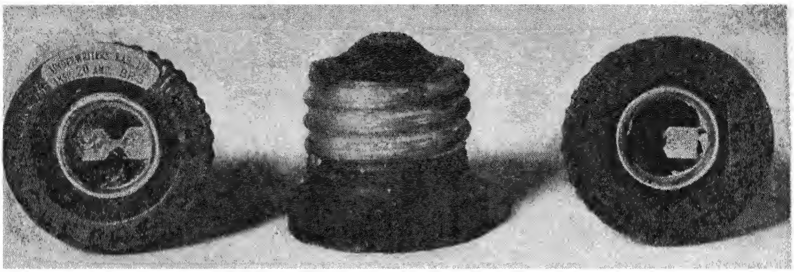


FIG. 260. Screw-plug fuses. The fuse at the right has been "burned out."

wires will become very hot. They may even become red-hot. Then they will burn away the insulation, and they may even set the house on fire.

All the electrical current that goes through the wires in a house must also go through a fuse. Sometimes it goes through several fuses. Each fuse is a piece of soft metal. Usually it is inside a porcelain or glass "plug" that is easily screwed into the circuit. This soft metal fuse is made just the right size to carry a safe current without getting hot. But as soon as a dangerous amount of current goes through it, the fuse metal gets hot, melts, and automatically stops the current. The fuse keeps the wires in the house from getting too hot because it breaks the circuit if too much current is passing through the wires. When the metal in a fuse melts, a new fuse must be put in. Usually you will find one pair of large fuses for all the electricity used in the house, and several pairs of smaller fuses for the circuits in different parts of the house. Some houses are now being equipped with switches that

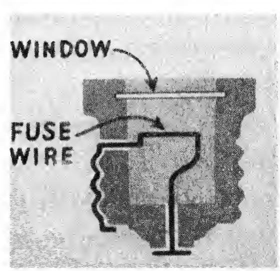


FIG. 261. A fuse

fly open when the wires are overloaded with electricity. When the danger is over, someone can close the switches again instead of having to put in a new fuse.

Near the main switch and fuse box you will usually find the electric meter that measures the electric energy used in that building. You can see a little aluminum disk inside the meter. When this disk is turning, some electricity is being used. As more and more lights or motors are turned on, the disk turns faster and faster.

From the switch and fuses, wires run in pairs to all parts of the house where the current is used. The wires in all carefully wired houses are well insulated. They are covered first with cotton thread, then with rubber, and outside the rubber with cotton cloth. Even insulated wires are never allowed to touch wood or nails. In some houses they are fastened to porcelain "insulators." Where they go through a wall, they are put inside porcelain tubes or other special tubes. However, the best way is to run the insulated wires inside metal pipes or in "armored cable" (Figures 259 and 262) to metal boxes where lights, switches, or "outlets" are located. When wires are inclosed in metal pipes or cables, rats and mice cannot chew off the insulation.

The lights and other devices that use the current are all connected in such a way that part of the current of electrons can go through one light and right back to the generator. Another part goes through another light, and so on (Figure 263). This plan of connecting devices to-

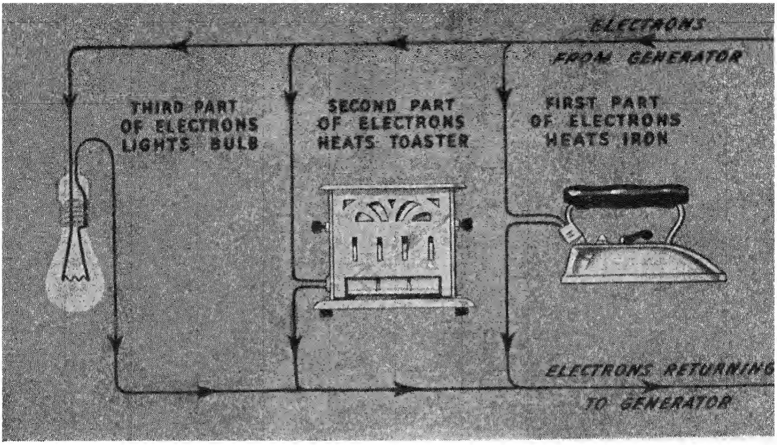


FIG. 263. How a number of electrical appliances may be connected in parallel so that electrons can flow through any one of them alone

geth r is known as a *parallel circuit*, or parallel connection. When several devices are connected "in parallel," you can turn on one light or one toaster without having everything else going. However, each light or toaster or iron that you turn on requires that much more current. If you turn on too many devices, enough current will go through the wires to melt the metal in the fuse. If this happens, you should turn off some of the devices before you put in a new fuse.

Sometimes two wires touch each other, or a boy sticks a piece of metal into a light socket. Then the electricity can go back to the generator without going through a lamp or a toaster or a sweeper. This is called a *short circuit*. Because the current does not have to flow through some electrical device, there is very little resistance to the flow of the electrons; so the amount of current that can pass through the wire is greatly increased. When this happens, so large an amount of electricity can get through that usually a fuse melts. You should be careful to find the trouble in the wiring before putting in another fuse, or the new will be "blown" (melted), too.

One of the two wires that go to an electrical device

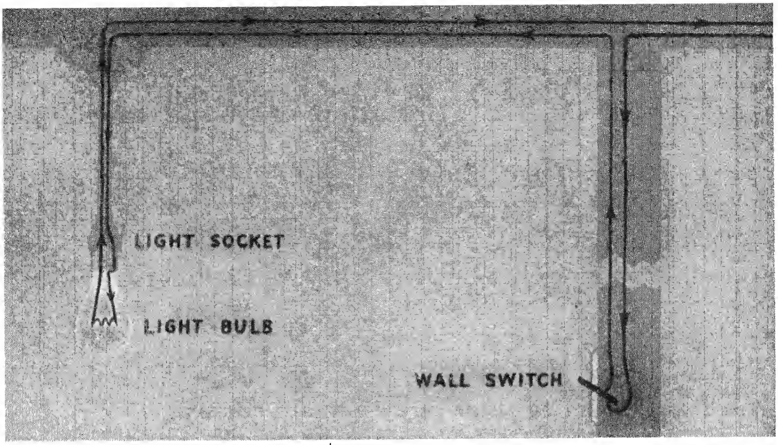


FIG. 264. How a light is connected in series with a switch. Does the drawing show the light on or off?

usually goes through a switch of some kind, so tha' we can turn that device on and off without affecting ner devices. Sometimes the switch is in the socke' right above the light bulb. Sometimes it is in the wall near the door. Can you see how the wires would need to be connected to have the switch near the door?

Notice that a switch and a lamp are connected to each other so that the electrons go through one and then through the other when the switch is closed. This method of connecting devices together forms a *series* circuit; that is, the devices are connected *in series* (Figure 264). Each electron must go through every device in the series or there is no current for any of them. You have already learned that when devices are connected in parallel, some of the electrons go through each device without going through the others.

You have now seen some of the ways by which electric currents are controlled to make them useful and safe in our homes. The conductors and insulators are arranged to form a path for the electrons. Then we connect in the circuit, either in series or in parallel, the devices for using the current and for regulating it. Switches open

and close the path according to our wishes. Fuses are used to shut off the current when it becomes dangerous. If you understand these facts, you can use electricity and electrical devices much more intelligently.

Self-Testing Exercises

1. What are the important parts of a simple electric circuit? Make a diagram to show how they are connected.

2. Why do at least two wires go to each electrical device?

3. Why are fuses used in the electrical system of a house? Why do they sometimes "blow"?

4. Why are electric-light wires carefully insulated?

5. What is a short circuit? What usually happens in a house-lighting system when there is a short circuit?

6. (*a*) How are the wires arranged when several devices are connected "in parallel"? Use a diagram in your answer. (*b*) How are devices connected in series? Draw a diagram.

7. Make a diagram to show how the wires are arranged to turn a ceiling light on and off with a switch in the wall.

Problems to Solve

1. Are the fuses in a house circuit in series or in parallel with the lights?

2. Make a diagram to show how the wires, switches, and fuses would be connected to supply three different lighting circuits inside a house.

3. If you have electric wiring in your home, study the wires, switches, meter, and fuses to see how they are connected. Then make a diagram of as much of it as you can find out about.

4. Take a light socket to pieces and find out how the electricity gets to the lamp and how it is turned on and off.

5. Fuses that screw into sockets have numbers on them—5, 10, 25, etc. What do these numbers mean? You may have to ask about this problem or read about it to find the answer.

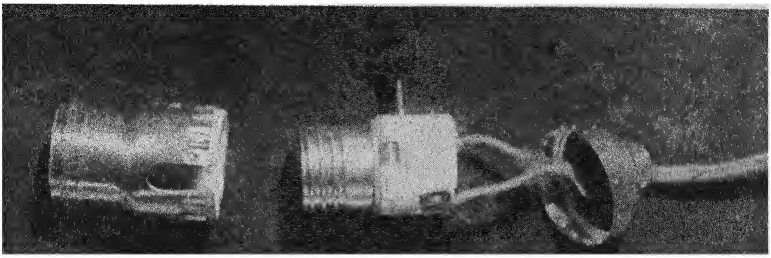


FIG. 265. Parts of the ordinary light socket. Such sockets are often easily repaired if you know how to take them apart. But you must be sure that the current is off.

6. If you had to put a new light socket in the place of a worn-out one, how would you protect yourself from a shock?

7. When a fuse blows, some people put a one-cent piece behind the used fuse to carry the current instead of getting a new fuse. Why is this dangerous?

8. Christmas-tree lights are frequently connected in series. What disadvantage do you see in this plan? What advantage?

9. Take a push-button apart to find out how it works.

Problem 3:

HOW DO WE USE CHEMICAL CHANGE TO MAKE ELECTRICAL CURRENT?

HOW CAN YOU MAKE ELECTRICITY BY CHEMICAL ACTION? You now have a general picture of how electricity behaves and how we control it for our uses. You will next find out what really happens to make the electrons flow through the circuits. Scientists know several different ways of making electrical currents, but most of our current is produced by two kinds of devices. These two kinds of devices are cells, or "batteries," and generators. In cells, chemical substances are arranged in just the right way to make the currents. In generators, magnets and wires are arranged so that by turning the generators we get current.

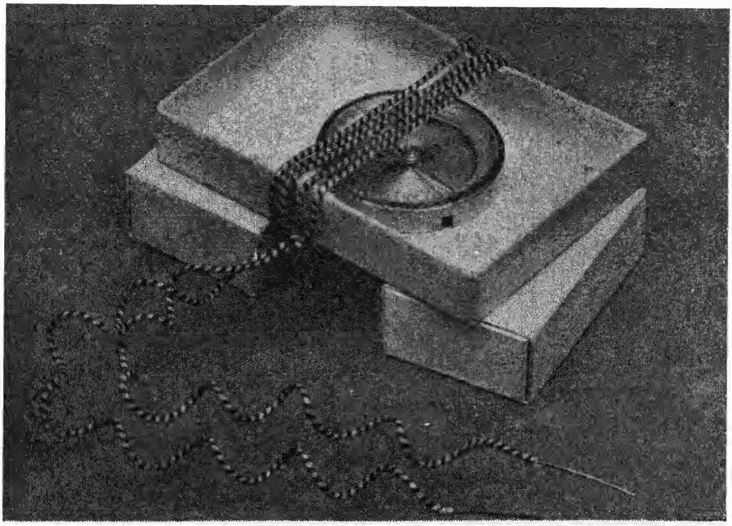


FIG. 266. A home-made galvanometer for Experiment 16

Electric energy is much cheaper when it comes from generators, but generators are heavy machines. They must also be kept turning all the time when we need current. As a convenient source of small amounts of electricity, inventors have made cells called "dry batteries," or dry cells. We use them where we cannot get small amounts of current from wires connected to generators. You have probably seen flashlight batteries and other dry cells many times. Do you know what is in them and how they are able to produce an electrical current? Could you go to your own kitchen and make a cell that would really work?

EXPERIMENT 16. *How Can You Make a Simple Cell?* (*a*) For this experiment you will need some convenient way of telling when you have an electric current. Get a cardboard or wooden box just large enough to hold a magnetic compass. Wind some insulated copper wire of convenient size around the middle of the box about five times. Fasten the wire so that it will not unwind. Leave long ends to connect to your cell.

Place your compass in the coil and turn the box so that the compass needle and the coils point in the same direction.

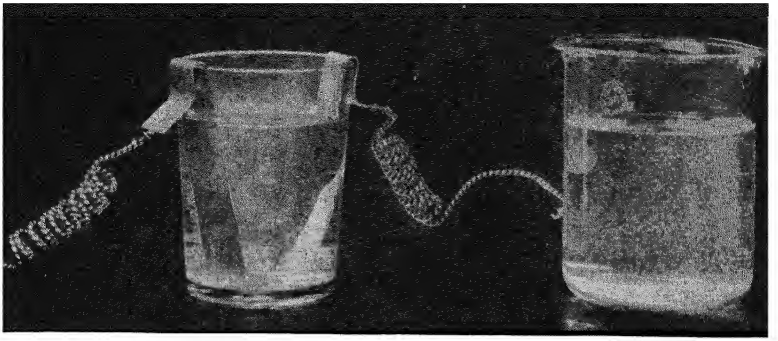


FIG. 267. A home-made simple cell for Experiment 16

Support the box on its lid or on two books or boxes so that it is level and is not easily shaken. The device that you have just made is called a *galvanometer*. When a current of electricity passes through the wire, the compass needle will swing to the right or to the left, depending on which way the current is flowing through the wire.

b) Fill a glass tumbler or small jar about two-thirds full of dilute sulphuric acid. (To dilute the acid, pour one part of concentrated acid slowly into ten parts of water in a large beaker, stirring with a glass rod or tube as you do so. ***Caution:*** *Never pour water into concentrated sulphuric acid.*) With a hammer and small nail make a hole near one corner of a strip of zinc at least one inch wide and five inches long. Fasten the bare end of an insulated wire in the hole so that it makes good contact with the zinc. Prepare a strip of copper in the same way. The wider your piece of copper, the better the cell will work. Bend the strips to hang on the edge of the tumbler.

Connect the copper and zinc to your galvanometer so that any current they make will go through the coils around the compass. Hang the copper strip in the acid. Does anything happen to the strip or to the compass? Lower the zinc strip into the acid, but do not let it touch the copper. What happens to the compass? Notice the bubbles on the zinc and the copper. They are hydrogen.

Notice that the current gets weaker and weaker. This weakening of the current is caused by bubbles of hydrogen collecting on the copper plate. The hydrogen prevents the liquid from coming into contact with the plate and thus stops

the flow of electrons. The cell can usually be made strong again by rinsing the copper plate in water and then wiping it off with a piece of paper towel. (Always rinse the plates before laying them down.) A cell of this kind with a rather large copper plate should give current enough at first to ring a small bell or buzzer. Try it.

c) Try two copper plates to see if they make a current. If you have strips of other metals, like iron, tin, aluminum, and lead, try them in the place of the copper and zinc to see whether other metals make a current.

d) Try a solution of vinegar, table salt, or ammonium chloride (sal ammoniac, that you can buy at a drug store), instead of the sulphuric acid. Do other chemicals make a current? Try a sugar solution.

These experiments with metals and solutions give you the important ideas about making electric current by chemical action. You noticed that no current was produced if both plates were of the same metal. Thus, for a cell that will make electric current, you need to have two plates, or *electrodes*, of different metals and a solution of a chemical that will make a chemical change in one of the metals. Zinc and copper will make more current than most pairs of metals.

In the cell you made, the sulphuric acid changed some of the zinc of the zinc electrode into zinc sulphate. The zinc sulphate dissolved in the liquid. When this happened, a great many electrons were left on the zinc plate. This gave the zinc plate a negative charge, and the electrons repelled one another through the wire to the copper plate. (Remember that like charges repel.) In this way a current of electrons flows from the zinc electrode through the wire to the copper electrode. At the copper electrode the electrons cause still another change that produces hydrogen.

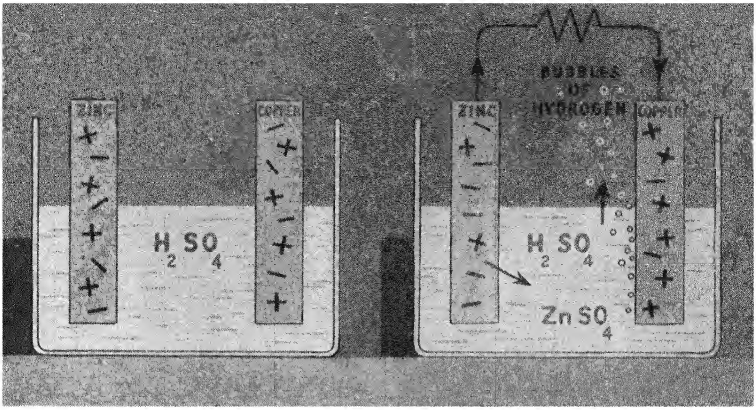


FIG. 268. The diagram at the left shows a cell at the instant the electrodes are put in the solution. From your study of this page and of page 288 you should be able to explain the right-hand diagram fully.

You can show the chemical changes that go on in your simple cell by writing them in a chemical sentence, or equation. In words the equation looks like this:

Zinc and sulphuric acid (containing chemical energy)	(change) → (into)	Zinc sulphate, hydrogen, and electrical energy

In chemical symbols the equation looks like this:

$Zn + H_2SO_4$ (containing chemical energy)	→	$ZnSO_4 + H_2$ + electrical energy

In every electric cell one of the plates is used up or changed chemically. In your cell the zinc plate is used up; it serves as fuel to make the cell work. Notice also that the chemical energy of the zinc and sulphuric acid is changed into the energy of the electric current. Your simple cell soon becomes useless because of the bubbles of hydrogen that cover the copper electrode. The bubbles of hydrogen gas act as insulation around the copper; therefore little current can get through. Let us see how a better kind of cell works.

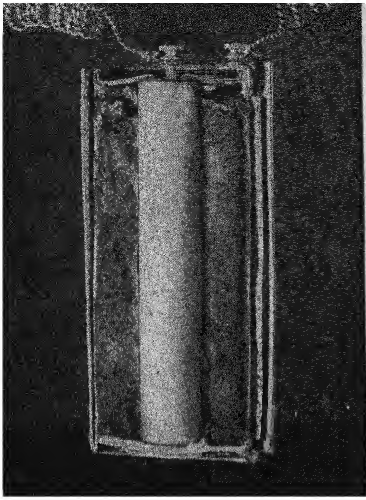


Fig. 269. A cut-open dry cell

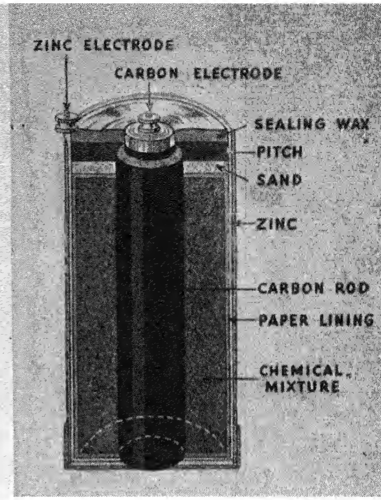


Fig. 270. Parts of a dry cell

How does a dry cell work? The battery in a flashlight is usually made of two or three small dry cells. You have already used a large dry cell in Experiment 15. Get a worn-out flashlight cell or a full-sized dry cell and see how it is made.

Experiment 17. *How Is a Dry Cell Constructed?* Remove the paper or cardboard covering from your worn-out dry cell. The metal can is made of zinc. Is it smooth and whole, or have the chemicals "eaten" holes in it? Lay the cell on a newspaper. With a hammer and dull chisel or screw-driver cut a slit down one side and around the bottom. Unroll the zinc and take the cell to pieces, layer by layer. Compare it with Figures 269 and 270. What takes the place of copper in this kind of cell?

The active chemical in a dry cell is ammonium chloride. (Did you smell ammonia in your cell?) The pasty mass in the middle contains water to dissolve the ammonium chloride. When the cell is delivering current, hydrogen collects on the carbon electrode in the same way that it did on the copper electrode of the simple cell. As you know, this will stop the chemical action, and the cell will

grow weaker. To prevent the collection of hydrogen on the carbon, a chemical called manganese dioxide is used. This chemical removes the hydrogen by combining with it to form water.

If a cell gives a large amount of current for a time, it becomes weaker because the manganese dioxide cannot combine with the hydrogen as fast as it is formed. After a rest the cell will again give a large current because the hydrogen has had time to combine with the manganese dioxide and to change into water. For this reason it is better to turn a flashlight on and off occasionally rather than to keep it lighted for a long period of time. The action of the dry cell is very much like that of the simple cell. The ammonium chloride combines slowly with the zinc. As a result of the chemical action, electrons are left on the zinc electrode, and the zinc electrode becomes negatively charged. Part of the electrons are then repelled through the wire that makes the circuit.

As in the simple cell, the zinc acts as the fuel and is used up. As soon as holes appear in the zinc covering of a dry cell, the water evaporates, and the cell is "worn out." Boys sometimes collect used dry cells and renew them for experiments. To do this they make nail-holes in the sides of the cells and set each cell in a separate jar of water. The water soaks into the cell, and there are enough chemicals and zinc left in the cell to give current for some time.

Dry cells are a convenient source of current because they are light to carry and because no liquid can spill from them when they are turned upside down. The chief difficulty is that we must buy new cells whenever holes are eaten through the zinc can. How many uses of dry cells do you know?

FIG. 271. Are these cells connected in series or in parallel? What voltage is being produced?

HOW IS ELECTRICAL PRESSURE BUILT UP IN A BATTERY? You have probably heard the term *volt* used to describe an electrical current. For example, you may have heard of a 110-volt current. What does this mean? Perhaps the best way to explain this is to compare it with a water system consisting of a tank connected with pipes. If the tank is half full of water, it will force a certain amount of water through the pipes. This is because the weight of the water has a downward pressure, as you learned in *Science Problems, Book 2*. The water flows through the pipes because of this pressure. The greater the pressure, the more gallons per minute will flow through the pipes.

Now let us see how this helps us understand an electrical current. As the chemical change in the atoms of zinc causes electrons to collect on the zinc plate, they build up a pressure, an *electrical pressure*. They do this because, as you know, the electrons have a negative charge and repel each other. Electrical pressure is measured in *volts* (named after the Italian scientist, Volta, who made the first cell). Thus, volts of electrical pressure are somewhat like pounds per square inch of water pressure. Scientists

have an exact definition of a volt, but it will be better for you to remember that a dry cell gives about 1.5 volts of pressure. The simple cell you made in Experiment 16 gave a pressure of a little more than one volt.

When we need more electrical pressure (or *voltage*) than one dry cell will give, we connect two or more cells together in a series to make a *battery;* that is, a battery is simply two or more cells connected together. Large dry cells, used to operate many small electrical devices, are usually connected as shown in Figure 271. Each cell adds 1.5 volts until we get the voltage we need. In a flashlight battery a piece of brass on top of the carbon rod is pushed against the bottom of the next zinc can (Figure 272). Thus they are really connected just like the cells in Figure 271. When cells are connected in series, the electrons go through one cell after the other just as they do through a switch and a light when they are in series.

Where current is used for lighting homes, it is usually brought into the house wires with a pressure of 110 volts. That is, the pressure in the house wires is about as great as would be produced by 75 dry cells connected in series.

Self-Testing Exercises

1. What parts are needed to make a simple electric cell?
2. When a simple cell is made from zinc, copper, and sulphuric acid, does the zinc or the copper receive a negative charge?

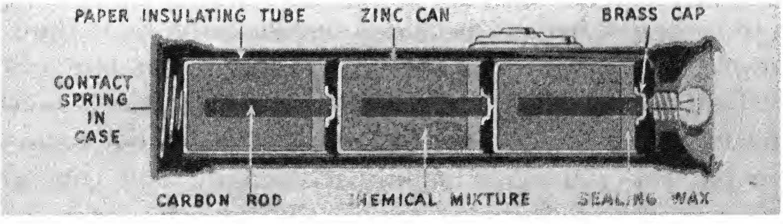


FIG. 272. Parts of a three-cell flashlight

3. What substances undergo a chemical change in a simple cell? In a dry cell?

4. Would you expect to get any electrical current from a simple cell made with an iron nail, a piece of an aluminum pan, and some sulphuric acid? Tell why.

5. (*a*) Make diagrams to show how four dry cells are connected together in series. (*b*) What is the advantage of connecting several cells in series?

6. What is the difference between a cell and a battery?

Problems to Solve

1. Is the positive connection of a dry cell in the middle of the top or at the edge? How do you know?

2. When you buy a flashlight, why do you need new batteries occasionally?

3. Is a dry cell really dry? Explain your answer.

4. Find out how cells are connected in *parallel*. For what purposes is the parallel connection used?

HOW DOES A STORAGE BATTERY WORK? Every time you "step on" the starter button of an automobile, a storage battery is connected with a motor that cranks your engine. Have you ever had to crank an engine when the storage battery had gone "dead"? If you have, you know that it takes a great deal of force. Unless you are very strong, you cannot do it, especially when the engine is very cold.

Ordinarily, the only attention a storage battery needs is to have distilled water added occasionally. Sometimes, however, the battery goes "dead." When this happens, it must be *charged;* that is, a current of electricity must be run through it. When this is done for a period of time, the battery will again supply a current. You can see that a storage battery differs from a dry cell. A dry cell cannot be recharged. When it is worn out, it must be


FIG. 273. Apparatus for Experiment 18

thrown away and a new one provided. Now let us find out how a storage battery works.

EXPERIMENT 18. *How Can You Make a Simple Storage Cell?* (*a*) Fill a tumbler or small jar two-thirds full of a solution of sulphuric acid in water (one part of concentrated acid poured slowly into three parts of water). Place in this solution two clean lead plates that do not touch each other. Connect the lead plates to a bell. Does it ring? Why?

b) Connect three dry cells in series and send their current through the lead plates and sulphuric acid for several minutes. Watch carefully for any signs of chemical action. Disconnect the dry cells. Lift the lead plates out and examine them. (***Caution:*** *Do not get the acid on yourself or on the table.*) Are the plates now alike or different?

c) Return the plates to the acid and connect them to an electric bell. The bell should ring for some time.

d) When the bell has stopped, disconnect it and send current through the lead plates again. Then see how long the storage battery will ring the bell.

Are you surprised to see how easily you can make a storage cell? However, you will be disappointed if you charge your cell and let it stand for a time. This simple cell will not remain charged very long.

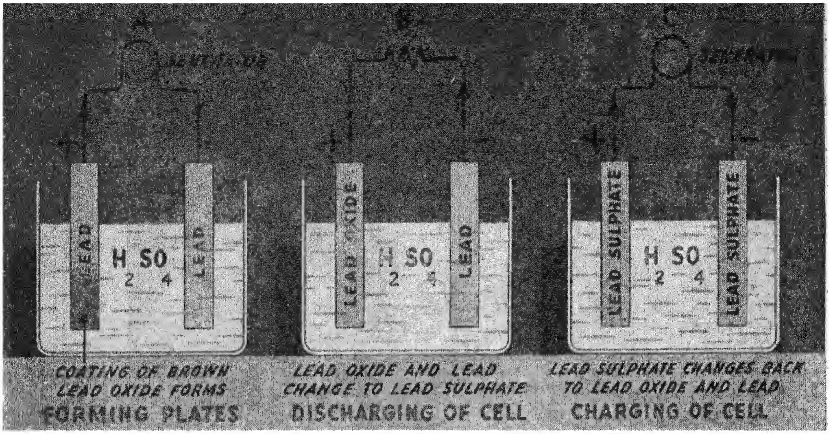


FIG. 274. Can you explain fully what happens in a storage cell?

The storage cell generates a current in the same way that your simple cell did. After you had sent the current through your lead plates, you found that one of them had a brownish covering. The other was a gray lead-color. The brownish material is an oxide of lead (PbO_2), formed because the current produces oxygen at that plate. Thus there are really two kinds of plates in the acid—one of lead oxide and one of lead (Figure 274 A). The plates have been formed and the cell is charged. When you connect the plates to the bell, it rings until the lead and the lead oxide are changed to lead sulphate. You are now discharging the cell (Figure 274 B). To charge the cell again, it is only necessary to send a current through the plates in the opposite direction (Figure 274 C), and the plates change back to lead and lead oxide. The storage cell will now ring the bell again.

Does the storage cell store electricity? If someone should ask you how to store some electricity, you would probably tell him to get a storage battery. But let us take a more careful look at what happens. The energy of the current that charges a battery causes a chemical change in the lead. This chemical change produces lead oxide on one of the plates. When this happens, the energy

of the electrical current is changed to chemical energy. Thus, a storage cell does not store electricity; it stores a compound containing chemical energy. This chemical energy is changed back into the energy of an electric current when you need it. But you cannot expect to get out as much energy as you put in. Ordinary storage batteries are from 65 to 75 per cent efficient; that is, they will give back only from 65 to 75 per cent of the energy used in charging them.

The storage cells we use in auto-lighting systems have in them the same materials you used in your simple storage cells. However, they are carefully constructed to give large currents for a long time. The plates are very large, and they are made in the form of lead frameworks, or *grids*. Into these grids spongy lead and lead oxide are pressed to make thick layers of active material. The plates are placed very close together in the cell with thin pieces of wood or rubber to keep them from touching each other. This kind of cell can be discharged and charged as many as 500 times before it wears out.

Each lead storage cell gives about two volts of electrical pressure. Most uses require a higher voltage. Therefore, if you examine the storage battery of a car, you will find that it is really a battery instead of a cell, for it is made of three separate cells connected in series by lead bars across the top. Since each cell gives a pressure of two

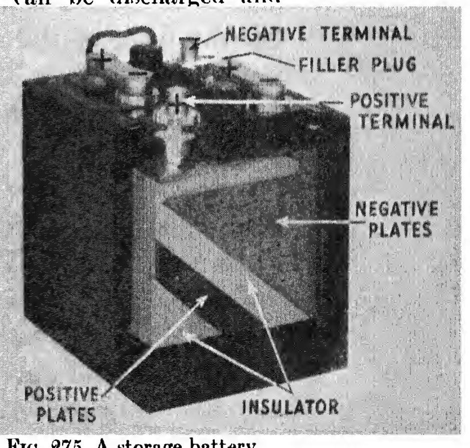


Fig. 275. A storage battery

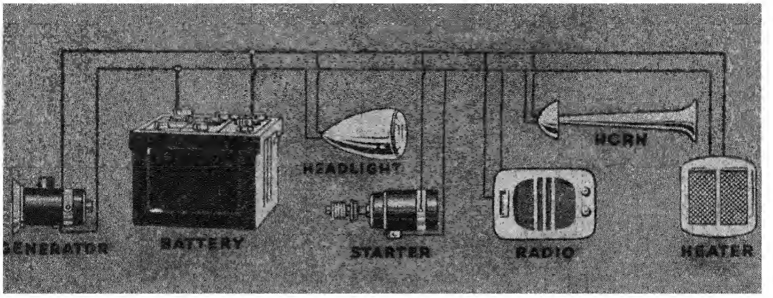


Fig. 276. What two ways of producing electrical current are shown in this picture? Into what kinds of energy is electrical energy being changed? Of course you know that electricity does not make heat for the heater. What does it do to the heater?

volts, the auto storage battery furnishes a total of six volts of electrical pressure.

In the automobile the storage battery is used to furnish current for several uses. When the motor is not running, the battery supplies current for the lights and horn, and for a radio and cigar-lighter, if the car is equipped with these conveniences. When you wish to start the motor, the battery gives current for the starter and spark-plugs. Then, when the motor is running, a generator attached to the motor sends current through the battery to recharge it so that it is always ready for use.

On the dash of the car is an instrument that shows whether the storage battery is being charged or discharged. Usually this instrument is an *ammeter;* that is, it is an *ampere* meter, or ampere measurer. The size of an electrical current or the rate of flow is measured in amperes just as we measure the rate of flow of water in gallons per minute. (The word *ampere* came from the name of a great French scientist, André Ampère.) A 60-watt light bulb in a house circuit usually requires about one-half ampere of current. An electric iron usually uses about five amperes of current. An automobile starter may use as much as 200 amperes of current for a short time while it is turning the engine.

When a car is running without lights, the ammeter should show that from ten to fifteen amperes of current are flowing through the storage battery to charge it. If the ammeter does not show "charge" when the car is running at a reasonable speed, without lights or radio on, something is wrong, and the car should be taken immediately to a service station. A good storage battery that is well cared for lasts quite a long time. Some of the water gradually evaporates, and some is decomposed by the charging current. This water must be replaced regularly (about every two weeks) with water that contains no minerals. Distilled water is usually used, but clean rain-water caught in glass or earthen vessels may be used. Ordinary well water or faucet water should never be used. Water from these sources contains minerals that will be deposited on the plates and ruin them.

In a fully charged battery, the hydrometer reading shows from 1270 to 1300. (Pure water would read 1000 on the hydrometer.) If the reading falls below 1150, the battery should be taken from the car and recharged at once. If the cells give readings that are very much different from one another, the battery probably needs repairs.

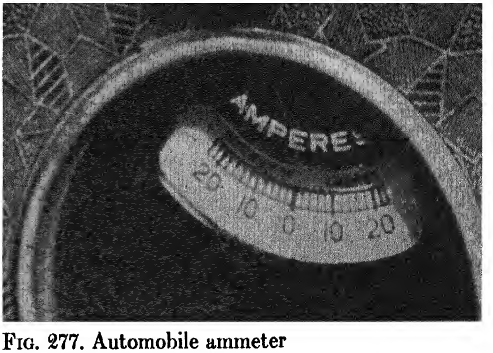


Fig. 277. Automobile ammeter

Storage batteries have several important uses in addition to their wide use in automobiles. A few trucks and automobiles are run by electric motors that get their current from large storage batteries. Some locomotives in mines are driven by current from batteries they carry. Tele-

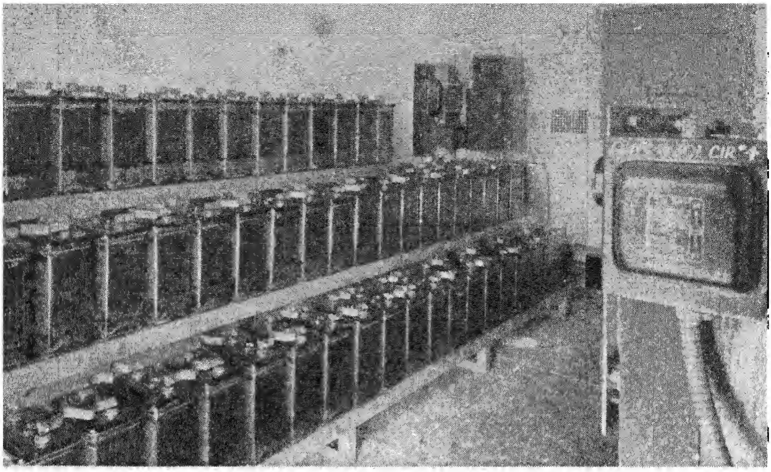


FIG. 278. Sometimes the electrical supply to buildings is interrupted. For this reason it is important that hospitals, factories, etc., have an emergency supply of electrical energy. This is available in the form of many storage batteries, which will furnish light for several hours. (Museum of Science and Industry, Chicago)

phone exchanges and small power-plants have batteries to supply current when the generators are not running or when extra power is needed. Country homes often get electricity for their lights from storage batteries that are charged by a generator run by a gasoline engine. Sometimes when they do not have electric lights, country people operate their radios with storage batteries that are kept charged by a small windmill.

Self-Testing Exercises

1. How is a simple storage cell like any other simple electrical cell? How is it different?
2. What is the form of energy that is stored in a storage battery?
3. Why is it correct to call the part you put inside a large flashlight a battery instead of a cell?
4. Tell why a storage battery is a very useful part of an automobile. Why is it better than dry cells?
5. How can a person tell when the battery in his automobile is fully charged?

6. Why does a battery service-man put distilled water in a battery instead of tap water?

7. Would you need more storage cells or more dry cells to give an electrical pressure of twelve volts? Tell how you know.

Problems to Solve

1. Why do we often use batteries instead of generators; that is, what advantages do batteries have?

2. Why do dry cells have paper covers?

3. Is it correct to say that the zinc plate in a simple cell dissolves as the cell is used?

4. What advantages has a storage battery over a battery made of dry cells? What disadvantages?

5. Can you taste electricity? Attach a wire to each post of a dry cell or each plate of a simple cell. Clean the other ends of the wires and touch both to your tongue at the same time.

6. Can you make an electric cell from a lemon? Stick a sharp knife into a lemon in two places. Then push a strip of zinc into one place and a strip of copper into the other. Attach wires to the strips and test to see whether a current is being produced.

7. Visit a battery service-station or repair shop and see what you can learn about the construction, charging, and repair of storage batteries.

Problem 4:
HOW DO WE USE MECHANICAL ENERGY TO MAKE ELECTRICAL CURRENT?

HOW CAN A MAGNET BE USED TO MAKE ELECTRONS FLOW? Cells and batteries are very convenient sources of electric current, and we use them a great deal. But if we had to depend on batteries for electric current, we could not afford to use electric lights, electric refrigerators, or vacuum-sweepers. The metal and chemicals that would be used up in the cells would be too expensive. We could have no large electric motors, no electric cars,

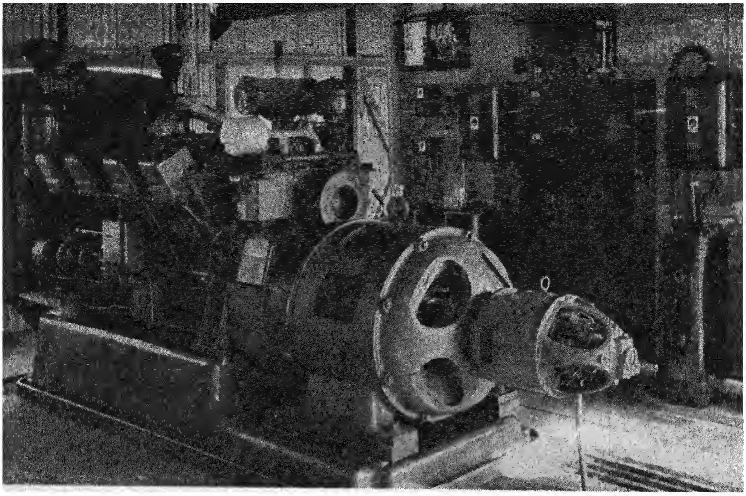


FIG. 279. This Diesel engine and electrical generator furnish the electricity to operate a dredge in a gold mine in Idaho.

or locomotives. More than 99 per cent of all the current we use in this country is made by generators.

Figure 279 shows a Diesel oil engine that drives a generator. The engine is at the left side of the picture and has many parts. You can see two generators at the right end of the engine. Each one has a ring on top of it. The smaller generator makes current for the magnets of the larger generator. These generators change the mechanical energy of the engine into the energy of an electric current. The current is carried through large copper cables to electric motors that operate machinery. How can such a generator make electrical current? As you have already learned, it was the great scientist Michael Faraday who discovered that he could use magnetism to make an electrical current. Every electrical generator uses the principle discovered by Faraday a little more than 100 years ago.

There are many ways of showing how magnetism makes electric currents. An easy way is to use a magnet, a small coil of wire, and a sensitive galvanometer.

FIG. 280. Apparatus for Experiment 19

EXPERIMENT 19. *How Can You Make Electric Current with a Magnet and Coil?* (*a*) If you do not have a sensitive galvanometer, you will need to borrow one. You can make the coil yourself, as follows: Trim the end of a board until it is about three-fourths of an inch thick and one and one-half inches wide. Round off the corners. It is better to have the board taper a little toward the end you use so that the coil will slip off easily. Wind at least 100 turns of No. 30 or 40 insulated copper wire in a compact coil about the end of your board. Leave the ends of the wire long. Slip the coil off the wood and tie thread around it in several places to hold the wire together.

b) Connect your coil carefully to the galvanometer. Hold the coil still and move one end of a magnet through the center of the coil. Is there a current? Remove the magnet, still watching the galvanometer. What happens?

c) Hold the magnet still and move the coil over one of its poles. Does this make a current?

d) Move the magnet or the coil more rapidly. Does the rate of motion make any difference?

e) Now use two magnets, with like poles of the magnets together. How does the strength of the current compare with that obtained with one magnet?

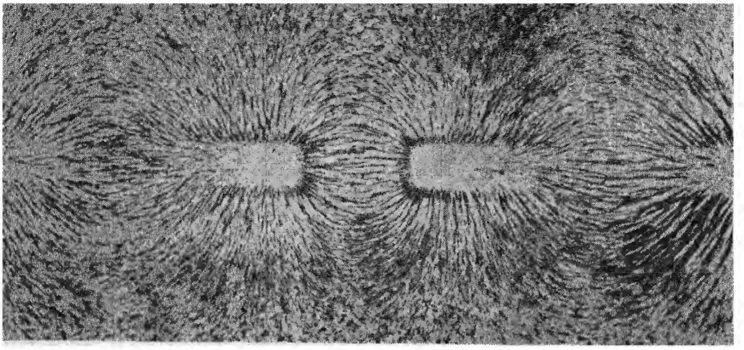


FIG. 281. In experiments with magnets you have probably shown the field of force with iron filings on cardboard or a glass plate.

Every magnet has a magnetic field around it, as you learned in *Science Problems, Book 1*. You may picture this field as many invisible lines running from one pole of the magnet to the other. Scientists call them lines of magnetic force. What Faraday found out was that electrons try to flow in a wire whenever the wire moves across the invisible lines of any magnetic field. It does not make any difference whether the wire moves or the magnet moves. The electrons will flow just the same.

In your experiment you moved a magnet through the center of your coil. Each of the magnetic lines around the pole of the magnet cut across 100 wires. Enough electrons flowed around your coil and through the galvanometer to make the needle move. You were using the principle discovered by Michael Faraday: *Whenever a conductor (wire) cuts magnetic lines of force, electrons tend to move along the conductor.* If there is a complete circuit, there will be an electrical current. The more lines of force that are cut in a second of time, the more current will flow.

You can easily see three ways to have more lines of force cut in one second. You used two of them in Experiment 19. In one part you moved your magnet more rapidly. In another you made a stronger magnetic field by using two magnets. The third way is to have more

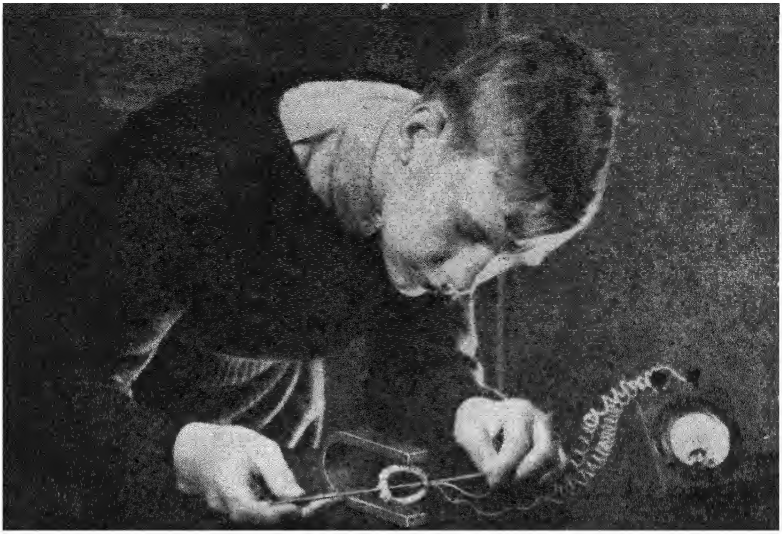


FIG. 282. Apparatus for Experiment 20

turns of wire in your coil. You will soon see that all three ways are used to get strong currents in generators.

HOW DOES AN ELECTRIC GENERATOR WORK? You can make a toy generator that will help you understand better how a generator works.

EXPERIMENT 20. *How Can a Coil of Wire Act Like an Electric Generator?* Get a straight piece of stiff wire at least six inches long. A steel knitting needle is excellent. Carefully push the wire through the ends of the coil you used in Experiment 19, so that you can spin the coil by rolling the wire shaft between your fingers. Connect the coil to the galvanometer. Hold it between the poles of a large U-magnet (Figure 282) or between the N-pole of one bar magnet and the S-pole of another. Rotate the coil rather rapidly and watch the effect on the galvanometer needle. Does the current go in the same direction all the time? What difficulty would you have in keeping your generator going all the time?

You have made your coil and magnet into an electric generator. The *magneto* shown in Figure 283 is a kind

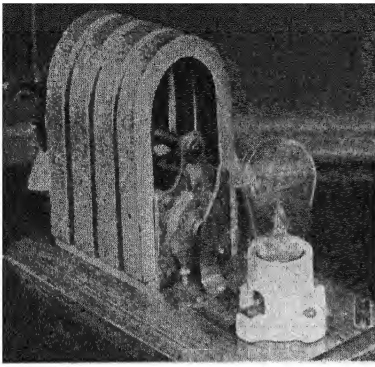


Fig. 283. A magneto

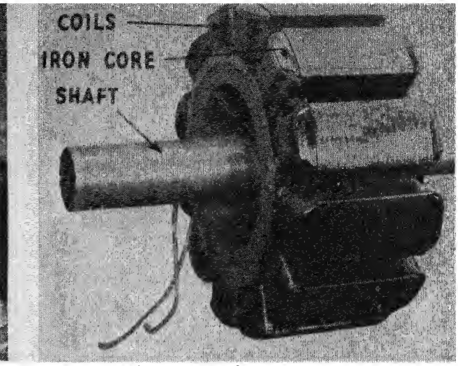


Fig. 284. Armature of a generator

of generator that uses several magnets and a coil with many more turns of wire than yours. The wire of the coil is wrapped around a piece of iron that rotates very rapidly between the poles of the magnets. The iron helps to make more lines of magnetic force right where the wires can pass through them because the lines of force can pass more easily through iron than through air. The rotating piece of iron with its many wires is called the *armature* (Figure 284). This magneto makes current enough to light the lamp you see connected to it. It will even give you a slight shock. Magnetos are used to ring the bells of many telephones in rural districts. Often they are used to supply the current for the spark-plugs of trucks and tractors.

When large amounts of current are to be generated, permanent magnets are not large enough or strong enough. Then electromagnets are used in the generators, and they are called *field magnets.* Figure 285 shows a simple generator that has an electromagnet to make a strong magnetic field. This generator will light an automobile headlight or ring a bell when you turn the crank.

You may have been wondering how a real generator is arranged to carry the current out of the rotating coil without having wires to get twisted as they did in your experiment. You noticed that the current from your

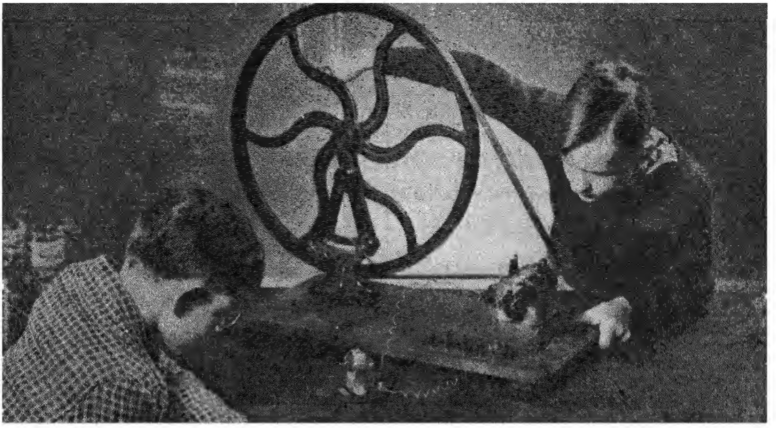


FIG. 285. A simple generator that uses electromagnets

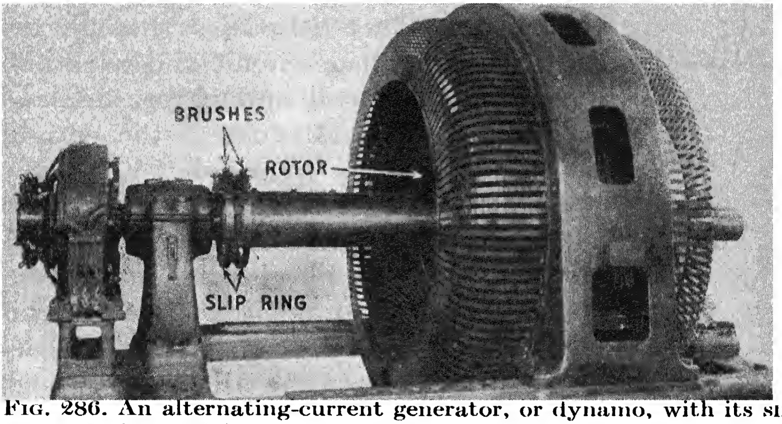


FIG. 286. An alternating-current generator, or dynamo, with its slip rings and brushes (General Electric photo)

generator was an *alternating*, or "back and forth," current. To use that kind of current, two rings, called *slip rings*, are usually fastened to the generator shaft, but they are insulated from it. Then one wire from the armature is fastened to each slip ring. A strip of metal or a block of carbon, called a *brush*, rubs on each ring. The current thus passes from the armature to the outside circuit through the slip rings and brushes. Can you see the slip rings in Figure 286?

But generators do not always make alternating current. To make *direct current*, that is, current that flows in the same direction all the time, the generator must have a *commutator*. The commutator for a simple generator is a single ring that is cut into two separate halves (Figure 287). One end of the armature wire is connected to each half. One brush also rubs on each half. During one half-turn the current goes one way in the armature coil and out through wire A to brush A. Then it passes through the outside circuit and back into the coil through brush B and wire B. Just as the current starts to go the other way in the armature coil, wire B slips from brush B to brush A and begins sending current out through brush A. In this way the current always goes out of the armature through brush A and in through brush B. In large direct-current generators there are many coils on the armature and many sections in the commutator. Such a generator gives a much steadier current than a simple generator.

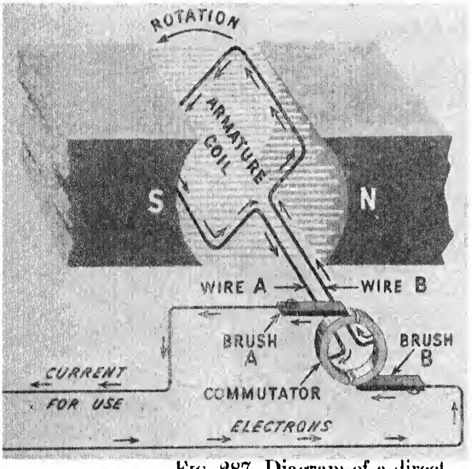
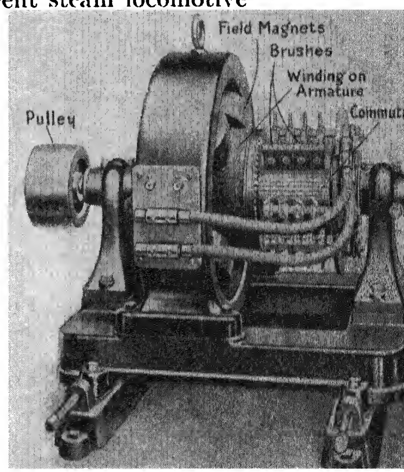


FIG. 287. Diagram of a direct-current generator

When you turn a magneto or generator that is not connected to an electric circuit, it turns very easily. You are not producing any electrical current. Then, if you push a button to close the circuit so that the generator begins to make a current, you will find that it is much harder to turn. That means that you are using mechanical energy to make the electricity flow. All electric generators

use mechanical energy to make electric energy. In Unit 9 you will learn how the energy of moving air, falling water, steam, and exploding gas is changed into electrical energy.

Electric generators are used in many different situations. Every modern airplane, tractor, truck, bus, automobile, and motor-boat carries an electric generator, and sometimes two or three. Every recent steam locomotive and every passenger car has a generator to make current for its lights. Those on the locomotives are run by small steam turbines, and those on the cars are run by belts from the axles. Many country homes have generators to make current for lights. Each large telephone exchange and radio station has several generators. Many pumping stations and factories make their own electrical current. Every large steamboat, ocean liner, and battle-ship has generators running day and night to furnish current for electrical devices all over the ship. You can now begin to realize why the electric generator is one of the most helpful inventions ever made. And all these different machines that use generators, as well as hundreds of others, have developed from a slight jerk of a needle that Michael Faraday saw in the year 1831!



rent dynamo

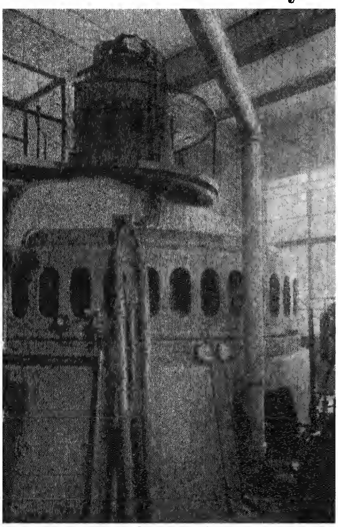
Self-Testing Exercises

1. A magnet is near a coil of wire. The ends of the wire are connected to a galvanometer. Suddenly the needle moves a little. What has happened to the wires in the coil?

2. Draw a simple diagram to show how a magneto can make a current flow.

3. Name three ways of strengthening the current caused by a magnetic field.

4. Tell how you could make a toy electrical generator.


alternating-current dynamo (Richard B. Hoit photo)

5. What kind of current does a single coil give when it is rotating in a magnetic field?

6. What is the use of slip rings on a generator?

7. Why do some generators have commutators?

8. Tell in one sentence what a generator does to energy.

9. List six different kinds of places where generators are useful.

Problems to Solve

1. Tell where you have seen electric generators and what their current was used for.

2. How does a large electric generator use the three ways of getting a strong current from a magnetic field?

3. Devise slip rings or a commutator or both for the coil and shaft you used in Experiment 20 and put them on. You will probably need to make some bearings for the shaft.

4. Would it be a good plan to make a generator entirely of copper? Why?

5. If a generator produces only 80 volts when 110 volts are needed, what are some ways of raising the voltage?

6. Does a generator turn harder when it is generating a small current or a large one or when it is not generating? Explain why.

7. Why can generators with electromagnets be made to produce larger currents than those with permanent magnets?

8. Why do we use storage batteries in automobiles and not on bicycles?

9. What would you think was the matter if you were turning a generator for an experiment and it suddenly began to turn very easily?

LOOKING BACK AT UNIT 5

1. Turn to the table of contents where the problems of this unit are stated. Copy each problem. Then answer it in about one-half page. Be sure to include in your answers the really important ideas.

2. Show that you know the meaning of each of the following words:

ammeter	*conductor*	*galvanometer*	*positive charge*
ampere	*electron*	*generator*	*series connections*
armature	*fuse*	*short-circuit*	*alternating current*
repel	*field magnet*	*insulator*	*storage battery*
circuit	*volt*	*electrical current*	*parallel connections*

ADDITIONAL EXERCISES

1. Can a wire be moved through a magnetic field in any way without causing electrons to flow? If so, how?

2. Make a diagram to show how a generator could be connected to send its own current through its field magnets. There are at least two simple ways of doing it.

3. Why does an alternating-current generator need some outside source of current for its field magnets?

4. Why does the needle of the galvanometer described in Experiment 19 move when a current goes through the coil? To answer this exercise, read in such reference books as physics texts or encyclopedias to find how galvanometers work.

5. Is the electrical resistance of a small wire more or less than that of a large wire?

6. Make a study of electrical insulators. What materials are used? What are their shapes? Why are they made of these materials in these shapes?

7. Find out how storage batteries are used in submarines.

8. What are the advantages of generators over cells? Of cells over generators?

9. Make a diagram of a circuit by which a bell will be rung by a push-button either at the back door or at the front door.

10. Work out a diagram of a circuit so that a bell in the kitchen and a bell upstairs would both be rung by the button at the front door.

11. Work out a diagram of a circuit by which the button at the back door will ring a buzzer and the one at the front door will ring a bell, but only one battery will be used for both.

12. What advantages can you see in using electricity to carry power to the wheels of a stream-line train or to the propeller of a boat? What disadvantages?

13. If a large coil is set upon a shaft that runs east and west and is provided with a commutator, why will it generate a current when it is rotated?

14. A metal plate with a positive charge and another with a negative charge are placed in a solution that contains both positive and negative particles. Why will the positive and negative particles be separated?

15. From a physics book learn the rule that tells the direction in which a current will flow in a generator coil. (In physics books it is customary to say that the current flows from positive to negative. The electrons really flow in the opposite direction.)

16. Learn from reference books how an "electric eye," or *photo-electric cell,* works and how electric eyes are used.

17. What is a *thermocouple?* How does it make an electric current?

18. Read about *induction machines* or *electrostatic machines.* How do they work?

19. Electricity can really be stored in a *Leyden jar.* Find out what a Leyden jar is and what can be done with it.

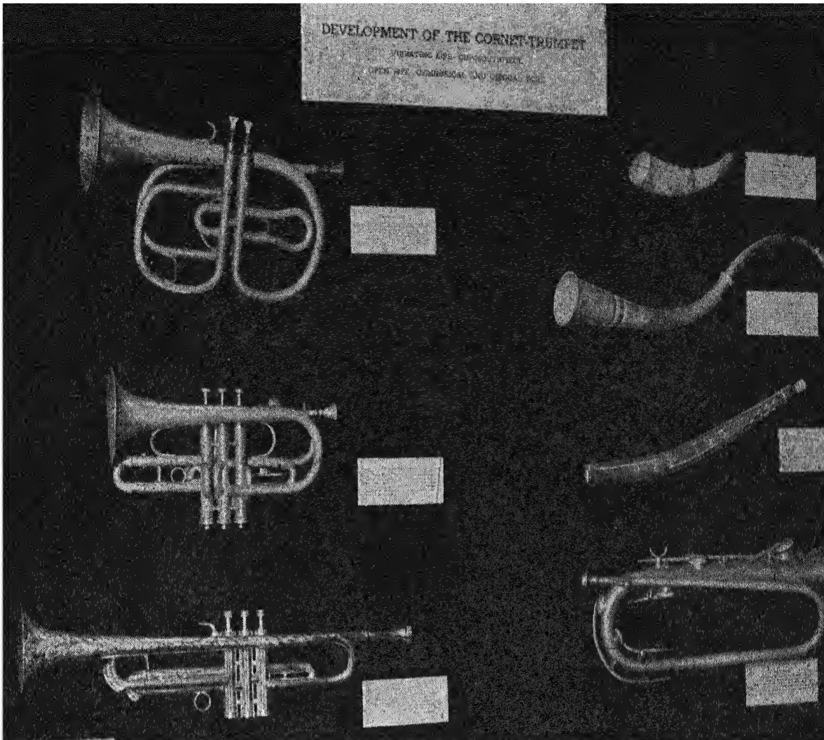


FIG. 290. As far back as we have any record in history, man has invented instruments to make sound. Most of these were musical instruments. Some of them were used to sound warnings, to send messages, and to call the people together for meetings. The picture on this page shows the development of the trumpet from the cow's horn of thousands of years ago to the fine brass and silver instruments of today. To make the many different musical instruments that we have, man has had to discover many things about the science of sound. In your study of this unit you will learn some of the things that he has discovered. (Photo from the Museum of Science and Industry, Chicago)

UNIT SIX

UNIT 6

HOW DO WE USE SOUND?

INTRODUCTORY EXERCISES

1. Listen to all the different sounds that are coming to your ears. Make a list of them and tell what causes each sound.

2. Can you tell the direction from which the sounds in Exercise 1 came without looking to find where they came from?

3. How does the sound of a bell get from the bell to your ears?

4. If you were standing 300 yards from a gun that was fired, could you hear the report as soon as you saw the smoke from the gun? Why?

5. What is the difference between pleasant sounds and sounds that are annoying?

6. Why are piano strings of different lengths and different diameters?

7. With your eyes closed, can you tell whether music is being produced by a violin, an organ, or a flute? How can you tell the difference?

8. Describe how you make sounds when you talk. Explain fully why you are able to make different kinds of sound.

9. How are you able to hear sounds?

10. What causes echoes?

FIG. 291. In this picture an *acoustical* engineer is using a delicate electrical instrument, called a *sound-level meter*, to measure the amount of noise in the room. (Celotex Corp. photo)

LOOKING AHEAD TO UNIT 6

PROBABLY the first thing you hear in the morning is the alarm clock. You lie in bed half awake and half asleep, undecided whether to get up. Your mother does not hear you getting up; so she decides to come and see about you. You hear her coming and get up before she gets there. You hear sounds which tell you that the rest of the family are up. Soon your mother calls you to breakfast.

At breakfast you listen to the family talk. Your father asks you if you have prepared your lessons, and you join in the conversation by replying. Before you realize how much time has passed, the clock strikes. This tells you that you must hurry, or you will be late for school. On your way to school you hear the sound of automobile horns warning you of the traffic. The policeman's whistle tells you when it is safe to cross the street.

At school the bell tells you when to begin work. You listen to the directions your teacher gives, and you hear your classmates recite. You hear the noise of many feet as the boys and girls go from class to class. During the music period you hear a phonograph reproduce musical

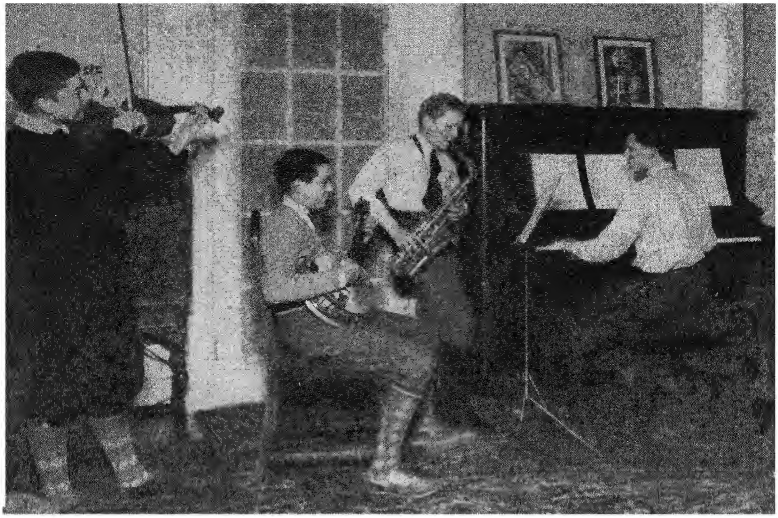


FIG. 292. Each of these boys is producing sound in a different way. What are the four different ways, and how are they all alike in one way? Why does each instrument make its own kind of sound? What does it mean to say that the boys are playing "in tune" or "out of tune"? This unit will help you answer these questions. (Ewing Galloway photo)

sounds, or perhaps you hear the school orchestra play. You recognize many of the different musical instruments by the kinds of sounds they make. The bass viol has a deep, low-pitched sound; the flute has a mellow sound; and the violin has a high, clear, singing tone. Probably your class sings with the orchestra. You are producing sound when you add your voice to that of the others.

These are but a few of the ways in which sounds have affected your life during a single day. They told you when to get up, when to cross the street in safety, and when to play. Sound enabled you to communicate with other people and to receive their thoughts. It helped you to learn about things around you and to enjoy them.

The importance of sound in our daily lives can hardly be overestimated. For example, think of a deaf person. As a child he has great difficulty in learning to talk because he cannot hear and imitate the sounds other people

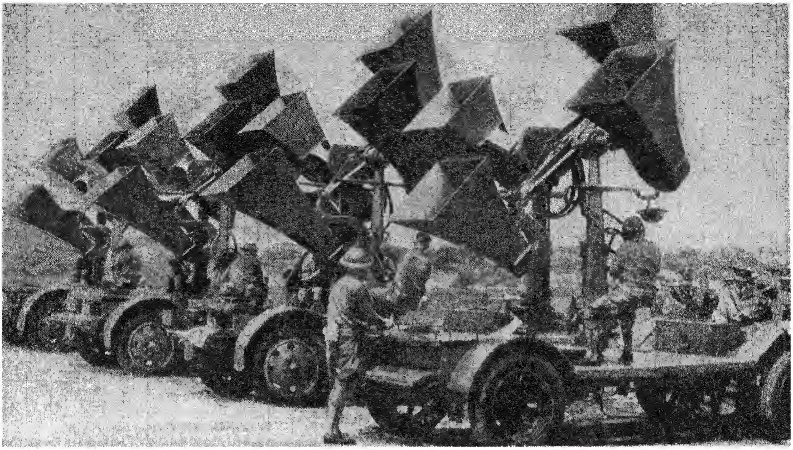


FIG. 293. These giant sound detectors are really mechanical ears. They gather sounds and, by the use of delicate electrical devices, make them stronger so that airplanes far up in the sky may be heard. (Ewing Galloway photo)

make. Such people often learn to communicate with each other by making signs with their hands. If you have ever watched two deaf people "talk with their hands," you realize what a handicap it is to be unable to hear. Often we read in the newspapers that a person was killed by a train because he was deaf and could not hear the warning sounds.

Think of some other ways in which sound is important in everyday life. Many families live in thin-walled apartment houses; so there must be some way of keeping down the noise in order to make their living conditions comfortable. In large offices the many typewriters and adding machines must work as quietly as possible. In auditoriums sound must be controlled in such a way that speakers and music can be heard clearly in all parts of these large rooms. Classrooms must be arranged so that the sounds from one room will not interfere with the work in another room. Loudspeakers are installed in large waiting-rooms of railroad stations to announce the arrival and departure of trains; and speaking tubes are often used in buildings

to communicate from one floor to another. In fact, sound is so important in modern life that *acoustical* (sound) *engineers* are often employed to help solve the problems that arise in controlling sound.

If you are like most other people, you are curious about things that happen about you. Why is it often several seconds between the time you see a flash of lightning and the time you hear the thunder? Why does a vase or other object setting on a piano often "rattle" when a certain note is played? What kinds of materials are used in insulating our buildings against sound? How are phonograph records made? What makes these records reproduce sounds? What causes the sound when a bugle is played? How do "sound phones" help partially deaf persons to hear? By reading this unit and doing the experiments you will learn some important facts about sound. Then you will be able to answer such questions for yourself.

Problem 1:
WHAT IS A SOUND?

HOW ARE SOUNDS STARTED? The sound of one of your classmates whispering in your ear is very different from the sound of a drum. The sound of a fire siren is not at all like a heavy crash of thunder. Yet all sounds, from the faintest to the loudest, are alike in some ways. This experiment will help you find out how all sounds are alike.

EXPERIMENT 21. *What Causes Sound?* (*a*) Place a drum on the floor or on a table with one end upward. Strike the skin covering. Quickly put the tips of your fingers on the skin. Can you feel it vibrating? Strike the drum again and quickly sprinkle some fine pieces of cork on the skin. What happens to the cork? What does this show you?

b) Make a rubber hammer by pushing a small wooden or iron rod into the hole of a rubber stopper. Use this hammer to

strike a tuning-fork. Quickly hold the fork near your ear. Can you hear a sound? Touch your finger to one of the prongs. Does it feel the way the vibrating drum head felt? Strike the tuning-fork again. Touch the tip of one of the moving prongs to the surface of some water. What is the result?

c) Fasten a stiff bristle or paper triangle about one inch long to the end of one prong of a tuning-fork with a drop of wax. Smoke a piece of window-pane with a candle flame until one side is entirely black. Lay the pane down with the smoked side up. Strike the tuning-fork and draw the tip of the bristle across the glass. What kind of pattern is traced by the bristle? What does this show you about the sounding fork?

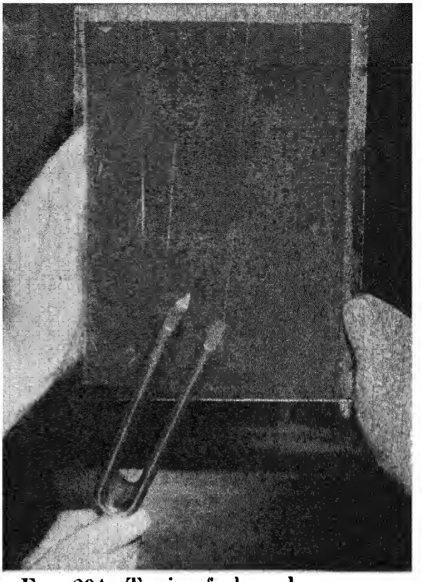


FIG. 294. Tuning-fork and plate on which it has recorded its vibrations

In Experiment 21 you found that each of the objects that produced sound was vibrating; that is, it was moving rapidly back and forth or up and down. You could feel the drum head vibrating when you placed the tips of your fingers on it. When you sprinkled the finely ground pieces of cork upon the vibrating drum head, they began to "dance" rapidly. You could see that the drum was making them bounce. When the tuning-fork was giving out sound, you could feel the vibrations of the prongs. The prongs also spattered the water when you placed them in it. The bristle on one prong of a tuning-fork showed you that the fork was moving rapidly back and forth.

Have you ever watched the clapper strike the gong of an electric bell? If so, you saw the gong quiver, or look blurred, because it was vibrating. When you are standing

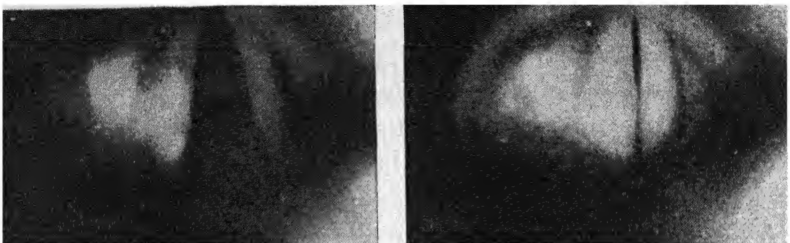


FIG. 295. These are actual photographs of the vocal cords, taken with the aid of a mirror placed in the back of the mouth cavity. At the left are shown the cords in position for breathing. At the right are the cords as they look when a person is speaking. (Photos by courtesy Dr. Mack D. Steer and Dr. Joseph Tiffin, Purdue University)

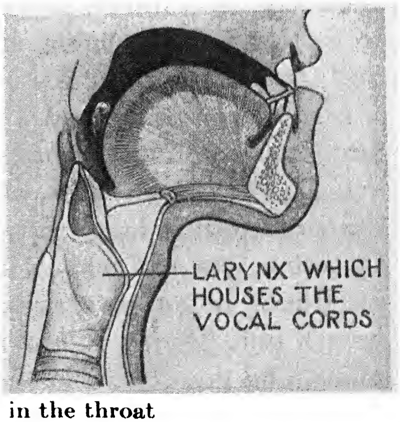
near a steam engine and the whistle blows, you can sometimes "feel" the vibrations that it causes. If you stretch a rubber band or a violin string tightly and pluck it with your finger, you can hear the sound it makes and see that it is blurred because it is vibrating. From these observations you can understand that all the sounds you hear are alike in this way: They are all produced by something that is vibrating.

We use sounds to communicate with each other. What vibrates to make the sounds of your voice? Place your thumb and forefinger on your "Adam's apple," or "voice-box," while you say a few words. As you speak, you can feel your "Adam's apple" move. Stretched across the inside of your voice-box, or larynx, are two folds of strong tissue. These folds are known as the *vocal cords*. It is the vocal cords that vibrate as you speak. From Figure 295 you can see that the outer edges of the vocal cords are fastened to the "frame" of the larynx. This frame is made of cartilage. The inner edges of the cords are free and can be moved closer together and farther apart by muscles. They can also be drawn tight by muscles.

To understand how the vocal cords produce sound, you can do a simple experiment. Stretch a wide rubber band rather tightly so that the two edges of it are close together. Blow between the two edges. If you do this just right, you will hear a sound produced by the vibrating rubber. This is the way the vocal cords produce sounds.

All the air you breathe in and out passes through your voice-box. As you breathe in, the vocal cords are drawn back with one on each side of the voice-box. The air passes between the cords and goes on down the windpipe into the lungs. However, when you talk or sing, something else happens. Tiny nerves from your brain are connected with the small muscles that control the vocal cords. When you want to speak or sing, your brain sends messages along these nerves to the muscles. The muscles pull the vocal cords together and draw them tighter, so that there is a narrow slit between them much like the slit between the rubber bands. Then, as your chest muscles force the air out of your lungs, the air makes the vocal cords vibrate. By making the cords tighter or looser the muscles can regulate the kinds of sound you make.

You must not get the idea that the voice-box with its vocal cords is the only part of your body that helps you make intelligent sounds. Your lips help you speak by changing the shape of your mouth. Your tongue and teeth also help in speaking. Your tongue, in particular, changes the quality of tone.



in the throat

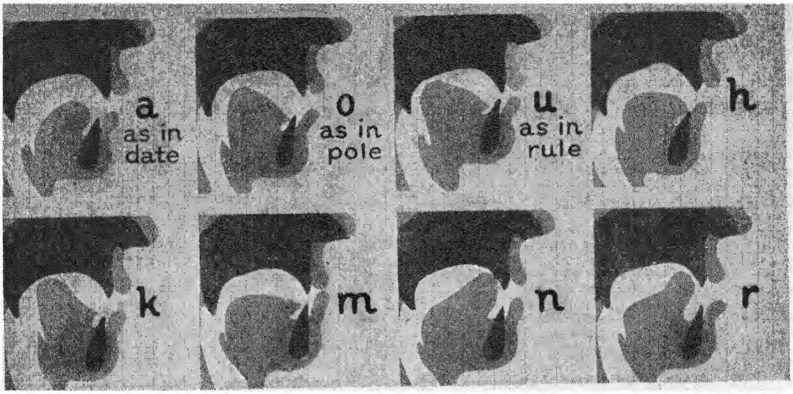


FIG. 297. Different positions of the lips and teeth during the making of different sounds. Notice how the tongue changes its position and shape to change the shape of the mouth cavity.

The muscles of your tongue make it thick or thin and change the shape of your mouth cavity. These changes give your voice its own quality and make it possible for you to pronounce words plainly. For example, pronounce the letters *a*, *o*, *u*, *m*, *j*, and *r* plainly. Note what happens to your tongue and lips when you say these letters.

Your nasal cavity helps you to give your voice quality, too. Repeat the letters mentioned above while you hold your nostrils shut. Do you notice how "flat" your voice sounds when your nose is closed? Look at Figure 297 and then look in a mirror as you pronounce different sounds to help you understand even better how your lips, tongue, and teeth help you form sound into words.

Most mammals have vocal cords. However, not all mammals produce sounds as human beings do. The vocal cords of pigs, cats, and cattle vibrate as the air is drawn into their lungs instead of when it is breathed out. Of course, you can make sounds as you draw your breath in. But it is not so easy to do as when you force your breath out. Try it. A few animals, such as whales, dolphins, and giraffes, cannot produce sounds at all.

Crickets, katydids, and grasshoppers make sounds in queer ways. Crickets and katydids have rough places

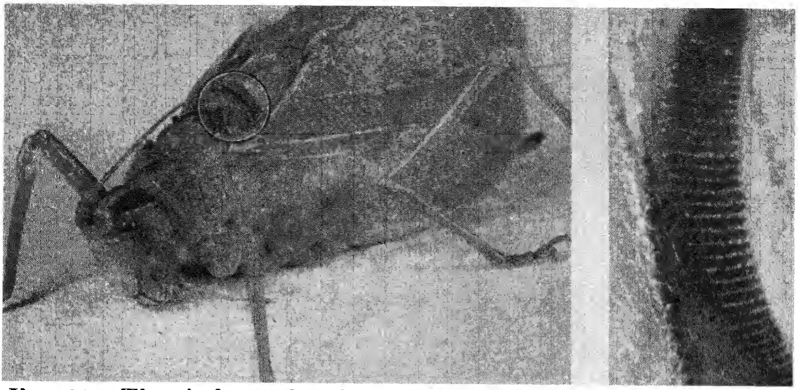


FIG. 298. The circle on the picture of the katydid shows the location of a file, which you see in the other picture, greatly magnified. (Photos by Paul R. Donaldson, Cruft Laboratory, Harvard)

known as files on one part of their wings near the inner bases of their wing covers. On the outer bases of their wing covers are hard parts, known as scrapers. By drawing the file of one wing cover across the scraper of the other wing cover they make their cheerful sounds. Some kinds of grasshoppers rub their hind legs together to produce vibrations, while others rub their hind legs against their wing covers.

Self-Testing Exercises

1. Which is true: *All vibrating bodies produce sounds. All sound is produced by vibrating bodies.* Give a reason for your answer.

2. Give examples from your own observations to illustrate what you have learned about the cause of sound.

3. Why do your vocal cords not get in the way when you draw your breath in?

4. Begin with the air in your lungs and tell what each part of your body does in making sounds as the air moves out.

Problems to Solve

1. Why is it sometimes difficult to speak after you have been running or are very excited?

2. Make up and try an experiment of your own to show that sound is produced by vibrating bodies.

FIG. 299. Apparatus to show that sound cannot travel through a vacuum

WHAT CARRIES SOUND? When you are in the open, you can hear someone call you for quite a distance even though there seems to be nothing to bring the sound to your ears. When a player in the center of a large football fields shouts loudly, people sitting on all sides of the field can hear him. How does sound travel? What carries it to your ears?

An experiment worked out by scientists helps us find out what carries sound to our ears. Study Figure 299 or, if you can, set up apparatus like it. The glass jar (called a *bell jar*) stands on the plate of a vacuum pump. The joint between the bell jar and the plate is made air-tight by means of soft wax.

The alarm clock is placed under the bell on a thick pad of cotton, and is set so that it will "go off" in a minute or two. When it rings, it can be heard plainly. Then the clock is set to "go off" in five minutes, the jar is placed over it, and it is sealed up again. As much air as possible is pumped from the bell jar, and, when the clock rings again, you can see it vibrating on the cotton pad, but you cannot hear a sound!

This experiment shows that air carries sounds. When air is in the jar, you can hear the bell ringing. When there is a good vacuum between the clock and the jar, you cannot hear the alarm at all. You cannot hear it because there is almost no air to carry the vibrations that are made as the clapper strikes the gong.

Perhaps you have heard people say that Indians and certain animals can tell when someone is approaching, even when the person is too far away for the sound of his steps to be heard. You may have heard that you can tell when a train is approaching (before it gets close enough to hear it through the air) by putting one of your ears to the rails. It would be dangerous to try this experiment on a railroad track. If you know of a side-track that is seldom used, it will be safe to try an experiment there. Have one of your classmates walk far down the track so that you cannot hear him tap on the rail with a small stone. Then put one of your ears to the rail and see whether you can hear him when he taps on the rail. You can do a similar experiment in the laboratory.

EXPERIMENT 22. *Do Solid Substances Transmit Sound?* (*a*) Put your ear against the end of a long wooden table. Have one of your classmates scratch gently on the other end of the table. Can you hear the scratching sounds? Remove your ear from the table. Can you hear the scratching sounds now? Why?

b) Strike a tuning-fork and hold it up in the air. How plainly can you hear it? Remove one end from a cigar box. Have someone hold a long iron or steel rod upright with one end of it resting on the top of the cigar box. Strike the tuning-fork and place the handle of it against the other end of the rod. How plainly can you hear it now? Try to explain why.

In this experiment you found that you could not hear the pin scratching or the tuning-fork very plainly through

FIG. 300. In this experiment scientists are finding out how well the head bones conduct sound. The sound is being transmitted to the bone back of the ear and is being picked up in the bone of the forehead. Delicate instruments show how strong the sound is, both when it enters the bone and when it comes out. (Sonotone Corp. photo)

the air. The sounds they made were too faint. But you could hear these sounds plainly when they were transmitted through solids, such as wood or metal. Certain solids (compact solids in which the molecules are close together) transmit sounds. As you noticed, most of these solids transmit sounds better than air, for you could hear very faint sounds more plainly through the solids.

You have learned that air (a gas) and certain solids carry sounds. Now let us see whether liquids carry sounds.

EXPERIMENT 23. *Do Liquids Transmit Sound?* Strike a tuning-fork and hold it up in the air as you did in part *b* of Experiment 22. Can you hear it? Cut a hole in a large cork and fit the handle of the tuning-fork into it. Set a glass of water on the top of the cigar box you used before. Strike the tuning-fork and hold the cork against the surface of the water. How plainly can you hear it now?

In the experiment you could hear the tuning-fork much more plainly when you held the cork against the surface of the water. This was because the vibrations of the fork

were transmitted through the water to the cigar box. This box acted as a sounding-board and helped you to hear the sound, but the vibrations had to be transmitted through the water before they could reach the box. So, liquids as well as air and some solids carry sounds. The next time you are in a swimming pool, get at one end of it and put one of your ears under the water. Have someone tap two rocks together under water at the other end of the pool. You will be surprised at the loudness of the sound.

Because liquids carry sound, ships can communicate with each other through the water. This is called submarine ("under the sea") signalling. To send the signals, a part of the hull of a ship is made to vibrate. The receiving ship has delicate receiving instruments attached to its hull. In this way the first ship can send sounds through the water to the second one. Ships now find the depth of the water where they are by sending sounds down to the bottom and finding how long it is before the echo is heard. To do this, it is necessary to know how fast sound travels in the water.

Self-Testing Exercises

1. Tell in your own words what is shown by the experiment with the bell in a vacuum.

2. Give examples from your own experience to show that liquids, solids, and gases carry sounds.

Problems to Solve

1. Make up experiments of your own to show that solids and liquids carry sound.

2. Read in reference books about the *fathometer* and its uses.

HOW FAST DOES SOUND TRAVEL? Did you ever see an official at a race use a pistol to start the runners? If you were a long way from the starting line, you saw the flash from the pistol some time before you heard the

report. The runners had already moved quite a distance down the track before the sound of the pistol reached you. Perhaps you wondered about this.

A little over 100 years ago two Dutch scientists, Van Beek and Moll, figured out a way to find how fast sound travels in air. They placed two cannons on hills that were eleven miles apart and performed the experiment at night so that the flash of the cannons could be seen plainly. First a cannon on one hill was fired. Observers on the other hill recorded the time they saw the flash and counted the exact number of seconds until they heard the report. Then the second cannon was fired, and the results were recorded as before. They used two cannons in order to avoid any errors that might be caused by the wind. The results showed that sound travels about 1100 feet per second at ordinary temperatures.

More exact experiments show that the speed of sound in air at zero degrees centigrade (32° F.) is 1090 feet per second. In thinking about this experiment you must recall that light travels at approximately 186,000 miles per second. This speed of light is too fast to interfere with the results of the experiment with sound. Since that time other experiments have been done to show that sound travels faster in warm air than it does in cold air. The increase is two feet per second for each degree (centigrade) rise in temperature.

A few years after Moll and Van Beek did their experiment, two other scientists found how fast sound travels in water. They suspended bells under water from two ships that were eight miles apart and performed the experiments as the Dutch scientists did. They rang first one bell and then the other. Their results showed that the speed of sound in water is about 4708 feet per second, a

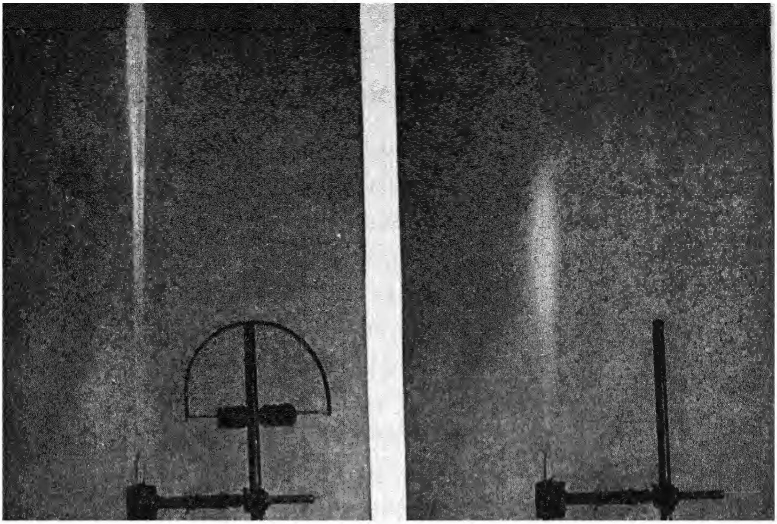


FIG. 301. These two pictures show what sound waves can do to a flame. At the left the gas flame is burning naturally. At the right the shape of the flame has been changed by jingling a string of iron washers near it. (Photos from Lemon's *Galileo to Cosmic Rays*, courtesy University of Chicago Press)

figure that we still accept as correct today. Later experiments show that sound travels even faster in solids. For example, it travels 15,422.5 feet per second in steel.

Self-Testing Exercises

1. Which carry sound fastest: solids, liquids, or gases?
2. How long does it take a sound to travel a mile (at 0° C.)?

Problems to Solve

1. Find out how far away a lightning flash is during a thunderstorm. To do this, record the number of seconds between the time you see the lightning and the time you hear the thunder. Multiply this number of seconds by 1100 (the speed in feet per second of sound in air at ordinary temperatures).

2. Ask your teacher to help you find the speed of sound on your athletic field. Use a starter's pistol with blank cartridges.

3. Find in some good reference book the speed of sound in different common materials.

WHAT ARE SOUND WAVES? Have you been wondering how a sound passes through the air? What goes from a vibrating object to your ear? Whatever it is, it must be able to pass through water and steel as well as through air.

Scientists have studied sound so carefully that they now understand very well how sounds move through materials. The results of one kind of experiment are shown in Figure 302. An electric spark, which made a cracking noise, was produced just back of the black spot in the center of the upper picture. An instant after the first spark a second one was produced. At the same time a camera film was exposed. When the film was developed, the scientists found that the flash of light from the second spark had taken a picture of something that looked like a circle in the air.

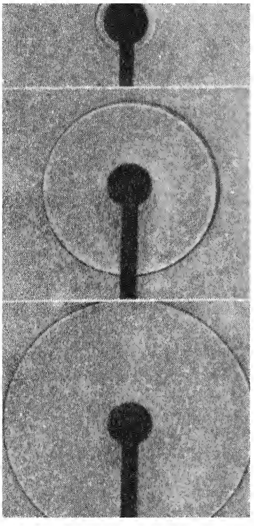


FIG. 302. Sound waves caused by an electric spark (Photos by Dr. A. L. Foley, Indiana University)

The scientists tried their experiment again, but waited a little longer to make the second spark. The second picture they made is shown just below the first. When they waited still longer, the "circle" was still larger, as shown in the lower picture. Sometimes they made a whole series of sparks to start the sound. Then the picture showed just as many circles as sparks. Something moved out in all directions through the air from each spark. This "something" is a layer of the air in which the molecules (particles) of air are closely packed together. It is called

a *sound wave.* When a tuning-fork is vibrating, it sends many sound waves out through the air in all directions. From a medium-sized fork the waves are about four feet apart.

However, you must not think that the molecules of air move from the tuning-fork to your ear. Each one just moves back and forth in its place. An experiment with a spring will help you understand how a wave can move without taking the air with it.

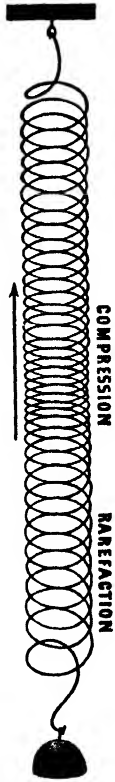


FIG. 303

EXPERIMENT 24. *How Do Sound Waves Move?* Get the spring out of a window-shade roller and fasten one end of it to a support (Figure 303). Fasten a weight to the other end of the spring. Near the lower end press together several coils of the spring; then let go of them quickly. Watch what happens along the entire spring. Repeat the experiment several times. Try to explain what happens.

The coils of the spring that you pressed together spread out and gave their motion to the coils next to them. These next coils were first pressed together and then spread out as they made other coils move in the same way. All of this happened so rapidly that a group of compressed coils seemed to move from the bottom to the top of the spring. You could see them seem to travel. Of course, the coils that you first pressed together did not move to the top of the spring. They stayed right where they were, near the lower end of the spring. All that they did was to spread apart far enough to press the next group of coils together. The motion of the compressed coil was what moved up the spring as it was transmitted from one coil to the other.

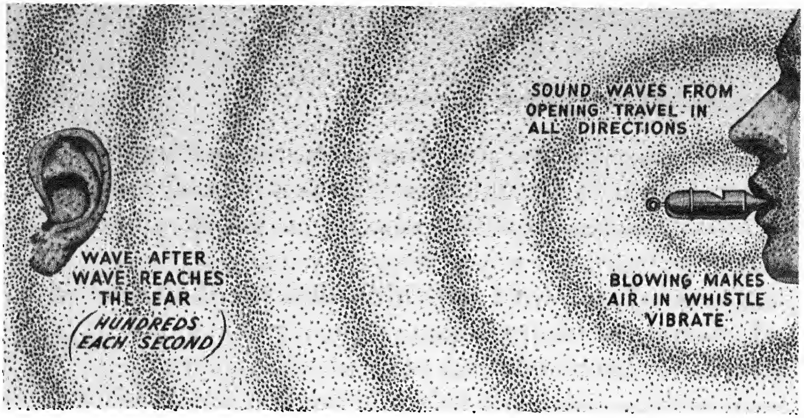


FIG. 304. How the vibrating molecules of air carry sound from a vibrating object to your ear. Notice that a complete sound wave is made up of two different bands of molecules.

Now suppose that each coil of the spring is a molecule of air and that your hand is the vibrating gong of a bell. The molecules of air around the bell are first pressed together as the moving gong strikes them. These compressed molecules spread out, much as the coils of the spring spread apart. When they do this, they press the next molecules close together. The second group passes their motion on to the third group, and so on until the vibrations reach the air in your ears.

The places where the air molecules are pressed together are known as *condensations*, and the places where they are spread farther apart are called *rarefactions*. A complete sound wave is made up of one rarefaction and one condensation. Study Figure 304 to help you trace a series of sound waves from their source to your ears.

You can see how waves travel each time you throw a stone in a quiet pond of water. The stone starts a whole series of waves that move out over the surface of the water. Any chips or leaves that are floating in the water bob up and down as the waves pass. But they do not move along with the waves. This shows that the water is not traveling from the stone outward. The wave in the

water is only traveling up and down. In the same way, a sound wave travels, but the molecules of air move only a little way. Notice that as a wave passes, the molecules of air do not move in the same direction as the particles of water. The water moves *up and down* at right angles to the direction in which the water waves are traveling. In the air, the molecules move *back and forth* for a tiny distance along the line in which the sound waves are traveling.

There is still another difference between water waves and sound waves. Water waves can travel only along the surface of the water. They do not go upward or downward. Sound waves move away from their source in *every* direction—upward, downward, and horizontally. Thus they take the form of spheres. You can picture these sound waves to yourself if you think of them as being shaped like soap bubbles. Imagine that you can blow one bubble inside another and do it very rapidly. Soon you would have a whole series of bubbles inside each other with all of them constantly getting larger as new ones are formed. In this way sound waves travel out from their source in the form of spheres. Because of this fact you can hear a sound in

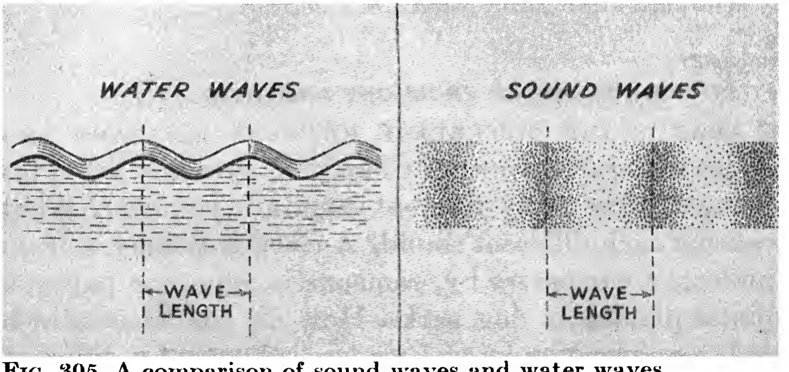


FIG. 305. A comparison of sound waves and water waves

any direction from a sounding body—upward, downward, and in any direction along the ground.

In liquids and in solids, sound waves travel in much the same way as in air. In these substances, however, the molecules are not so free to move as they are in air. Therefore they do not move back and forth as far as the molecules of air do while a sound wave is passing.

Self-Testing Exercises

1. Tell in your own words what sound waves are; then read your book again to see whether your explanation is correct.
2. Make a list of (*a*) ways in which sound waves and water waves are alike, and (*b*) ways in which they are different.
3. How can you tell that no substance travels from a sounding body to your ears?

Problem to Solve

How do waves travel along a rope? Tie one end of a clothes-line rope to a tree. Stand twenty or thirty feet away and draw the rope tight enough so that it does not touch the ground. Then give it one very quick up-and-down movement. This should start a wave that travels to the tree and back. Study its behavior. Does it come back the same as it went? Try sending two or three waves in a series.

Problem 2:
WHY DO SOUNDS DIFFER FROM ONE ANOTHER?

WHAT IS THE DIFFERENCE BETWEEN PLEASANT AND UNPLEASANT SOUNDS? Close your eyes and listen for a moment. How many different sounds do you hear? What is causing each different sound? A clock is ticking, a train is puffing, a car passes by, someone is moving a paper, a violin is playing, a dog barks. How do you know which sound is which? You know because each sound is different from the others. Some are pleasing, regular sounds; others

FIG. 306. People's ears vary greatly in the sounds they can hear; and as a person grows older, his ability to hear faint sounds slowly decreases. This delicate instrument, an *audiometer*, can measure very exactly just how keen your ears are. (Sonotone Corp. photo)

are "noises." Some are loud; others are soft. Some are shrill, or high-pitched; others are low. What is the real cause of all these differences?

It may seem foolish to ask what the difference is between a pleasant and an unpleasant sound. Certainly you can tell the difference between the sound your little brother or sister makes hammering on a drum and the sound a good violinist produces. An empty truck traveling swiftly down a rough highway does not sound at all like an orchestra. But you really need a knowledge of the science of sound to tell why some sounds are pleasant and others are unpleasant. When you clap your hands sharply, drop a book, or slam a door, you produce an unpleasant sound, or noise. When you hear someone playing a violin or flute well, you at once recognize pleasing sounds.

As you learned earlier in the unit, anything that produces sound is vibrating. In each of the kinds of examples you have just read, something was vibrating to make the

sounds. But why was one kind of sound pleasant and another unpleasant?

These differences in sound are the result of the kinds of vibrations produced in the air by the vibrating bodies. When you moved the tuning-fork and bristle across the smoked glass in Experiment 21, you saw that the bristle traced a wavy line. Also, you will recall that the tuning-fork made a pleasing sound as it vibrated. Study Figure 294 again, and you will see that the line traced by the bristle was a regular line. Its curves bent as far in one direction as they did in the other. Also, the curves were repeated over and over again in a regular pattern.

Now look at Figure 307. It shows a line traced by a body that was producing an unpleasant sound. From the picture you can easily see that these waves were very irregular. The curves did not bend as far in one direction as they did in the other, and they were not repeated over and over regularly as was the case with pleasant sounds.

Here is another example to help make sure that you understand the difference in the kinds of waves that make pleasant and unpleasant sounds. Figure 309 shows the graph of a sound wave made by a clarinet. When you first look at it, you may think that it produced an unpleasant sound. But if you study the figure carefully, you will see

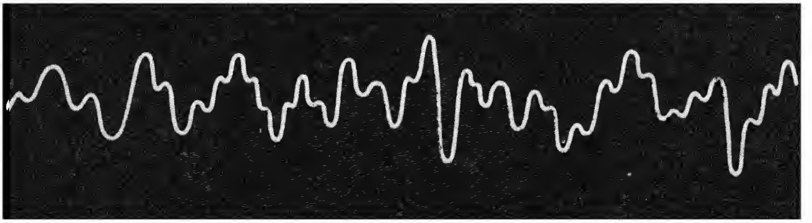


Fig. 307. A diagram of sound waves that make what we call noise

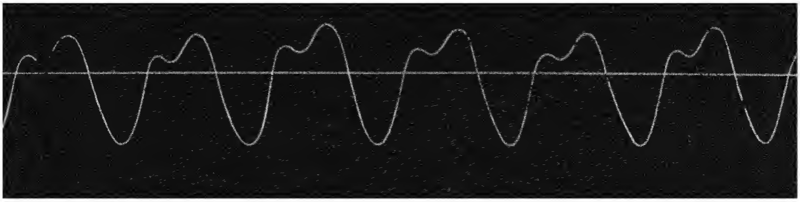


FIG. 308. Diagram of the sound wave sent out by a violin E string

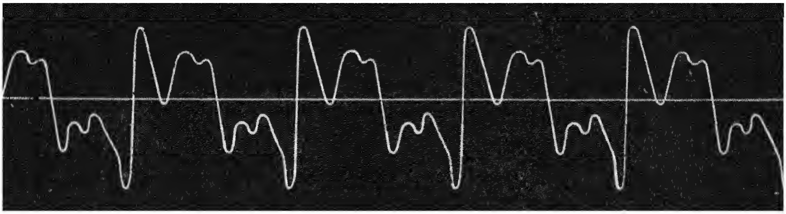


FIG. 309. Diagram of a high clarinet tone (Both diagrams as recorded by Dr. Dayton C. Miller, Case School of Applied Sciences)

that the waves are regular, even though each wave is made up of many smaller curves instead of simple ones. Notice the straight line drawn across each graph. These lines were put there to show you that the pattern made by these waves was repeated over and over at regular intervals.

During your study of this part of the unit you have learned several things that are of importance: (1) Unpleasant sounds are made by irregular sound waves. (2) Pleasant sounds are made by regular sound waves. Each wave is alike (as shown by the curved line it makes), and each wave is repeated at regular intervals. Now when you hear an object fall or a door slam, you will know why an unpleasant sound is made. And when you hear a pleasant sound, you will know how it is produced.

Self-Testing Exercises

1. Close your book and state in your own words the difference between pleasant and unpleasant sounds. Then read the book's answer again to see if you are correct.

2. Draw from memory (*a*) a line representing a musical sound, and (*b*) a line representing noise. Check as in Exercise 1.

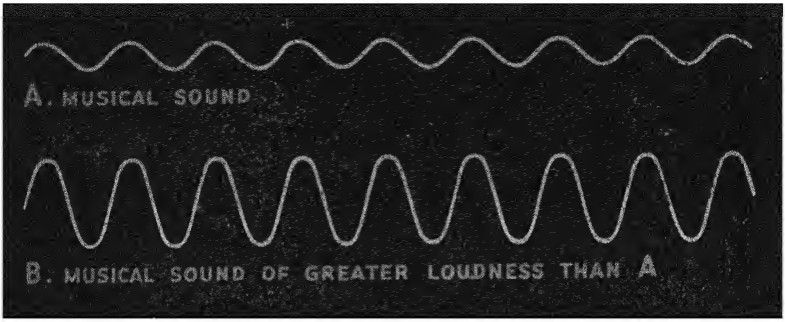


Fig. 310. A diagram of a soft sound and of a loud sound

WHAT IS THE DIFFERENCE BETWEEN "LOUD" AND "SOFT" SOUNDS? All your life you have been hearing sounds varying from the loudest crash of thunder to the faint tick of a watch. You are so familiar with sounds that vary in loudness that you probably have not thought much about them. However, the degree of loudness is one of the important things about sound. If you have ever sat in the back of a large auditorium and had a hard time hearing the speaker, you realize how important the loudness or softness of a sound is.

The loudness of a sound that you hear depends upon how far the sound waves move your ear drum in and out when they strike it. What makes some sound waves push your ear drum in farther that others? You learned in Problem 1 that sound waves are caused by particles of air (or other substances) that move back and forth for a tiny distance along the line in which they are traveling. Suppose you strike a drum a hard blow. The particles of air about it move back and forth for a greater distance than if you strike the drum very easily. The drum makes a loud sound. If you strike the drum an easy blow, the particles about it move back and forth for a much shorter distance, and the sound it makes is softer.

Figure 310 shows a tracing by a tuning-fork that was making a soft sound and another by the same fork when it was making a loud sound. As you learned in Problem 1,

TABLE 1. INTENSITY OF ORDINARY SOUNDS*

Intensity	Decibels	Kinds of Sound	Intensity	Decibels	Kinds of Sound
Deafening	120 110 100	Thunder, artillery Near-by riveter Elevated train Boiler factory	Moderate	60 50 40	Noisy home Average office Average conversation Quiet radio
Very loud	100 90 80	Loud street noise Noisy factory Traffic unmuffled Police whistle	Faint	40 30 20	Quiet home or private office Average auditorium Quiet conversation
Loud	80 70 60	Noisy office Average street noise Average radio Average factory	Very faint	20 10 0	Rustle of leaves Whisper Sound-proof room

*From Bulletin VI of the Acoustical Materials Association

sound waves spread out over a larger and larger area as they move away from their source. When the part of a sound wave that covered one square foot has spread until it covers two square feet when it reaches your ear, the part that strikes your ear will have only half as much energy. Therefore you will hear it with less loudness.

From what you have studied, you have learned that the loudness of sound depends upon two things: (1) how far the air molecules are moved back and forth by the vibrating body, and (2) the distance you are from the source of the sound.

In recent years scientists have made instruments for measuring how loud sounds are. The man in Figure 291 is using a *sound-level meter* to measure the noise of the office. This instrument measures the loudness of sound in units known as *decibels* (named after Alexander Bell, the inventor of the telephone). Continuous noise above

FIG. 311. Among some African tribes drumming is done with amazing skill. These people have worked out strange and complicated rhythms, and in ways that are still a mystery to white men, the tribal drummers send long messages from village to village. (Ewing Galloway photo)

50 decibels in schools, homes, stores, office buildings, and other places is believed to be harmful. This is one of the reasons why sound engineers try to find ways of reducing noise in the buildings where people live and work.

Self-Testing Exercises

1. State in your own words why some sounds are loud and others are soft.
2. Why is it useful to measure the loudness of sounds?
3. What is a *decibel?*

Problems to Solve

1. Sound waves become weaker because they travel outward from their source in the form of a sphere. How much weaker will a sound be at a distance of 20 feet from its source than at a distance of 10 feet? If you cannot see how to solve this problem, ask your mathematics teacher for suggestions.

2. Name three things that you can cause to give out sounds. Tell how you can make each one give out a soft sound or a loud sound as you wish.

WHAT IS THE DIFFERENCE BETWEEN "HIGH SOUNDS" AND "LOW SOUNDS"? Did your teacher ever tell your class that it was singing "off pitch"? What did he mean? Probably he sounded a "pitch pipe" or a note on the piano to help you sing as you should. The highness or lowness of tone is called its *pitch.* When you are singing "off pitch," you are singing a little too high or a little too low in comparison with the sound you should sing.

Pitch is another of the characteristics of sound. What gives sounds their pitch? Whether the pitch is high or low depends upon the number of sound waves that are produced by a vibrating body in one second. Scientists have learned many interesting things about pitch. You can learn some of them by doing the following experiment and observing very carefully to see what happens.

EXPERIMENT 25. *What Determines the Pitch of a String of a Musical Instrument?* (*a*) Get some rubber bands of various lengths and thicknesses. Stretch a short band tightly and pluck it. Notice the sound it makes. Stretch a long band of the same size as tightly as you did before. Pluck it and notice the sound it makes. How does it compare with the sound made by the short band?

Select another band and hold it loosely. Pluck it and note its sound now. Stretch the band as tightly as you can without breaking it. Pluck it and note the sound it makes. How are the sounds different?

Select a thick band and a thin band of the same lengths. Stretch them both equally tight and note the sounds they produce. Are they alike?

b) Ask someone in your class to bring to school a mandolin, a guitar, or a violin, or use a sound instrument called a *sonometer,* if you can get one. Pluck the smallest string and note the sound it gives. Hold the string down on the sounding-board so that the vibrating part will be shorter. Pluck it and compare

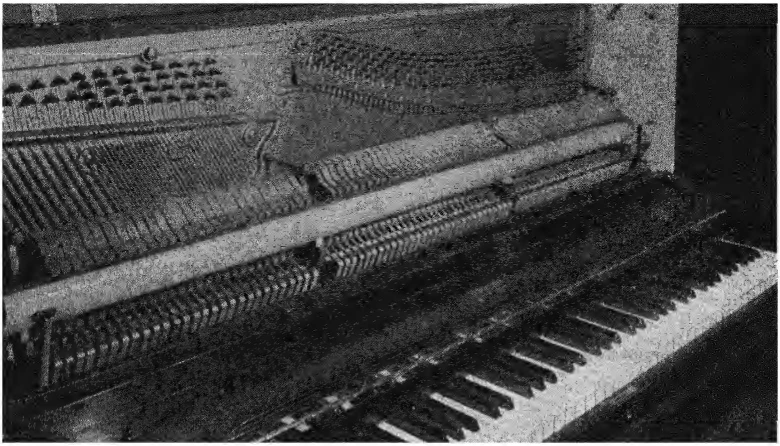


FIG. 312. Study this complicated arrangement of hammers, strings, and keys by which the piano is made to produce sounds. If you can do so, examine a piano at home or at school. (Kaufman-Fabry photo)

its sound with that of the full-length string. Begin plucking a string and tighten it each time you pluck. How is the sound different? Pluck one of the thin strings and one of the thick strings. Compare their sounds.

c) Your teacher will remove the front of a piano so that you can see the strings. Observe their thickness and length at different places. Have someone strike different keys and watch the strings vibrate. What kinds of strings vibrate fastest?

If you are a careful observer, you learned several important things about how to make sound higher or lower. You found that a short string gives a higher pitch than a long string of the same thickness and tightness. This is true because the short string can vibrate faster. You found, also, that when you tighten a string, you make it vibrate faster and therefore raise its pitch. When you loosen it, you make it vibrate more slowly; therefore you lower its pitch. If you have ever listened to someone tune a guitar or other stringed instrument, you have heard this happen. Recall what kinds of sounds the long, thick strings of a piano produce. A thick string vibrates slower than a thin string of the same length.

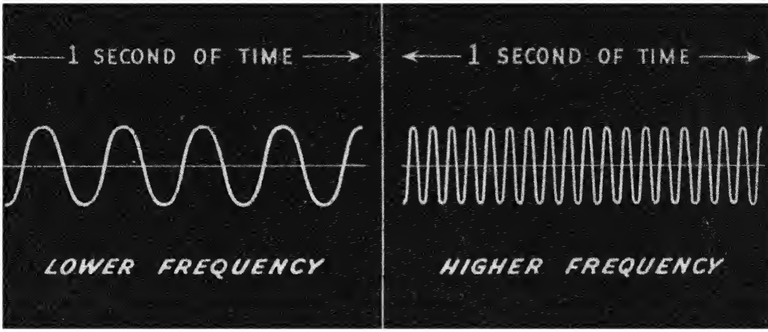


Fig. 313. This diagram will help you to understand what is meant by the *pitch* of a sound.

From your experiments you can see that the pitch of a sound depends upon how fast its source is vibrating. The number of vibrations per second is called the *frequency* of a sound. The frequency of a vibrating string depends on: (1) the length of the string, (2) the tightness of the string, and (3) the weight of the string.

People who play or manufacture musical instruments use the principles that you have learned to produce the proper kinds of sounds. For example, people who make pianos must know what kinds of strings to use, and a piano-tuner must know how tight to make the strings. Scientists have learned that the key called Middle C on a piano must vibrate 256 times per second if the piano is in tune according to a scale known as *Standard Pitch.* The lowest organ note has a frequency of 16 vibrations per second. The frequency of the highest piano note is 3500 vibrations per second.

A fire siren is a good example of the way the pitch depends on the frequency of vibrations. In a siren a jet of air is blown against a disc or other rotating device with evenly-spaced holes in it, or a rotating wheel with slits moves past openings in the stationary part. Puffs of air going through the openings produce vibrations. When the siren is rotating slowly, it makes a smaller number of vibrations per second; therefore the pitch is low. When

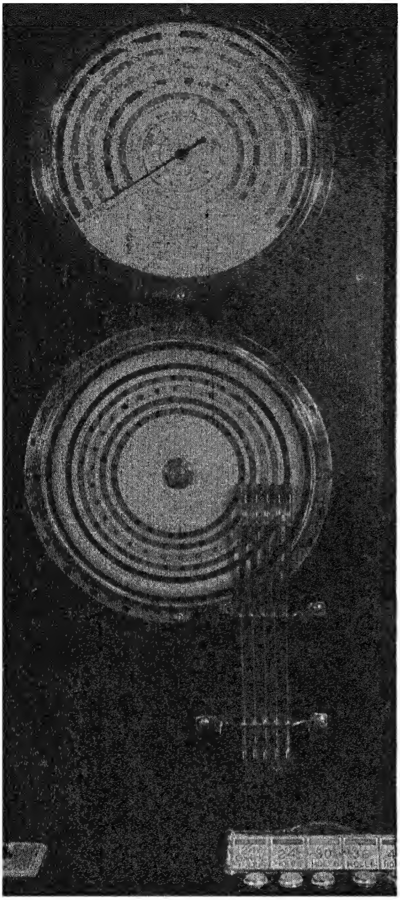


FIG. 314. How a siren works. Each metal tube shoots a blast of air through the holes as the disc turns. Each circle has a different number of holes in it. The speed of the disc and the number of holes determine the pitch, or frequency of vibration, caused by the blasts of air. The dial at the top registers the number of vibrations per second for each circle of holes. (Photo from Museum of Science and Industry, Chicago, courtesy of *Educational Music Magazine*)

the siren is speeded up, more vibrations are produced each second, and the pitch of the sound becomes higher. Examine a bicycle siren and try to explain why it changes its pitch as you ride at different speeds.

Self-Testing Exercises

1. Tell in your own words what is meant by the pitch of sound. What happens when the pitch of a sound is changed?

2. Without looking at your book show by means of rubber bands of different sizes that you know what determines the pitch of a vibrating string.

Problems to Solve

1. To help you understand pitch better, learn how a player tunes some stringed instrument, such as a guitar or a violin.

2. If a sound can travel 1100 feet per second, how far apart are the waves from a tuning-fork or string at middle C?

3. The highest note on a piano has a frequency of 3500 vibrations per second. How long are its sound waves in a room at 70° F. (about 20° C.)?

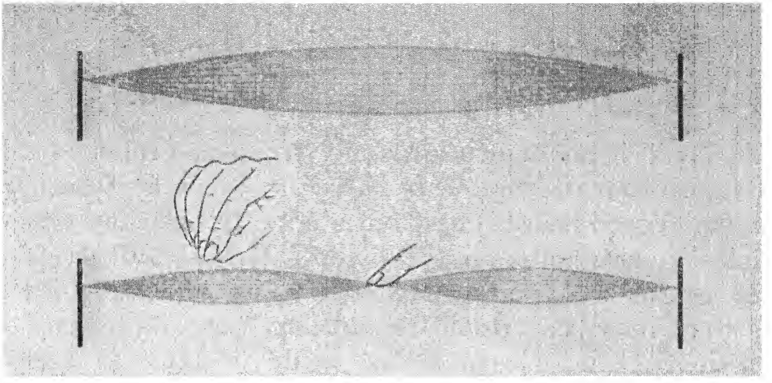


FIG. 315. This diagram will help you to understand how *overtones* are produced, as shown in Experiment 26.

4. How does a rise in temperature of the air affect the length of sound waves?

5. What are the "beats" that are heard when two musical sounds are at very nearly the same pitch? What causes them? Physics books will help you find the answer.

WHY DO SOUNDS DIFFER IN QUALITY? You can usually recognize your friend's voice over the telephone, even though he does not tell you his name. Two instruments, violins for example, may play the same note, but these two notes will not sound alike. You recognize your friend's voice by its *quality*. You know whether music is being produced by a violin, a guitar, or a piano by its quality. Quality, then, is another way in which sounds are different. An experiment will help you understand what is meant by the quality of sound.

EXPERIMENT 26. *In What Different Ways May a String Vibrate?* Stretch a coarse guitar or piano string between two upright supports. Pluck the string in the middle and watch it vibrate. Then hold one finger lightly on the middle of the string and pluck it one fourth of the way from one end. Quickly remove your finger and watch how the string vibrates now.

When you first plucked the string, you saw it vibrate in one large loop along its entire length (Figure 315). Also,

you heard it give out a low tone. When you plucked the string so that it vibrated in halves, you saw it vibrate in two loops and heard it give out a note that was one *octave* higher (eight notes on the piano). This sound was the first *overtone.* If you had made the string vibrate in three parts at once, you would have heard a second overtone.

Scientists have learned that strings of musical instruments can vibrate as a whole and at the same time can vibrate in parts. This means that a string can be giving out its lowest, or original, tone and overtones at the same time. This combination of sounds gives a string the particular quality that makes it sound different from others. Also, the number of overtones a string can give out depends upon where it is plucked or hammered. For example, the hammers of pianos are adjusted to strike the strings near the ends. At these places the strings produce a certain number of overtones and give the music better quality.

Your voice is different from that of other people because of its quality. Good singers learn to control their voices in such a way that good overtones are produced. The quality of music made by a violin depends upon the kind of overtones it produces. Of course, the kind of wood that is used in its construction and the way its bridge, the back of the violin, its ribs, and its sounding posts are made also help improve the quality of tone. Probably you understand now what a delicate task it is to make the best violins and why they cost so much.

Self-Testing Exercises

1. Why can we tell the sounds produced by one kind of instrument from those produced by another kind of instrument?

2. Explain what causes overtones. Make from memory sketches to show (*a*) how a string vibrates to produce its lowest, or original, tone, and (*b*) how it produces its first overtone.

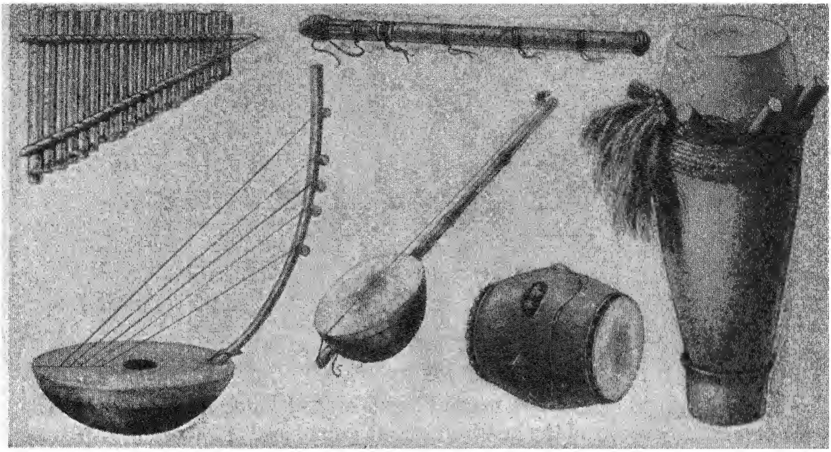


FIG. 316. In these musical instruments of savage tribes you see just about all the ways of producing sound that are used in our finely made instruments. Which of our instruments would you say are like these instruments in the way they produce sounds?

Problems to Solve

1. Try to produce the second, third, and higher overtones of the string you used for Experiment 26. To produce the second, hold the string with your finger tip on the edge of a rubber stopper at a point one-third of the way from one end. Then pluck it one-sixth of the way from the same end. Follow a similar plan for the higher overtones.

2. Why is an overtone a higher pitch than the natural, or fundamental, tone of a string?

3. Look at Figures 308 and 309. Why is the quality of a violin tone different from that of a clarinet?

Problem 3:
HOW DO MUSICAL INSTRUMENTS PRODUCE SOUND?

THE MUSICAL instruments in the picture above do not look much like the ones in Figure 317, do they? How long man has had musical instruments, we do not know. But many hundreds of years ago someone enjoyed playing on instruments like those in Figure 316. How many of the instruments do you recognize in the picture of the concert band on the next page?

FIG. 317. The fine concert band of Northland College, Wisconsin. How many of the instruments can you name? (Photo from S. J. Steen, courtesy of *Educational Music Magazine*)

Music may not seem so important in your life, but think how often you hear it. Probably you listened to the radio while you were eating breakfast this morning. Your school may have a band, orchestra, or glee club. You may enjoy playing some instrument. Since you hear music so often, you will find it interesting to know the scientist's definition of music and something of the ways in which musical sounds are produced.

Study the picture of the concert band shown above. You can easily see that some of these instruments are played by striking them, for example, the drums and the xylophone. Others are played by making strings vibrate; these are the violins, violas, cellos, bass viols, and harps. Still others are played by blowing into them. These three groups are known as *percussion* (meaning *to strike*) instruments, *stringed* instruments, and *wind* instruments. The wind instruments are further divided into *wood-winds* and *brasses*.

HOW DO PERCUSSION INSTRUMENTS WORK? Drums, cymbals, and other percussion instruments produce sound by means of vibrating membranes or metal parts. They are made to vibrate by striking them. Did you ever watch an orchestra player tune his kettle drums? He

tightens the membrane to make high sounds and loosens it to make lower sounds. A xylophone has a series of wooden bars of different lengths. As these are struck with the proper kind of hammers, they give out musical tones. Bells are one kind of percussion instrument. Others have metal bars or cylinders that are struck in various ways.

The next time you hear a band or orchestra play, it will be fun to look at the different kinds of instruments and decide the group to which they belong. Also, try to think how the sound is produced in each instrument.

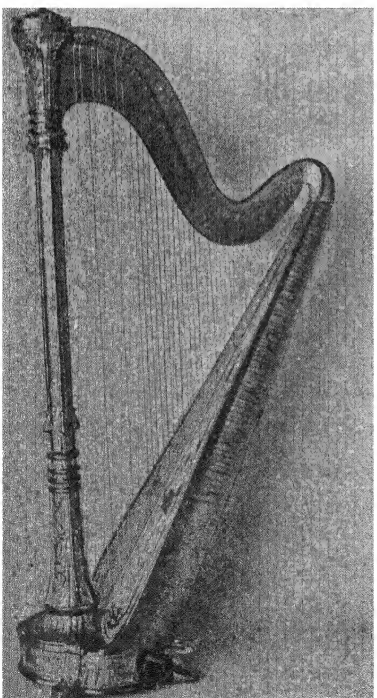
HOW DO STRINGED INSTRUMENTS WORK? Earlier in this part of the unit you learned that the lengths of vibrating strings, their tightness, and their thickness determine the pitch of the sounds they produce. In some kinds of instruments, such as guitars and banjos, the strings are set in vibration by plucking them with the fingers. Did you ever see a skilful player "pick" a banjo? If you have, you noticed that he used the fingers of his right hand to make the different strings sound. You also noticed that he made the strings shorter or longer by holding them down with the fingers of his left hand. The long, thick strings produced low sounds, and the short, thin ones made high sounds. On the harp there are many different lengths of strings; so the player has to know which strings to pluck to produce the sounds he wishes.

FIG. 318. Percussion instruments that you have probably often seen (Ewing Galloway photo)

Most of you have seen the key-

board of a piano, which has eighty-eight keys. There are also eighty-eight wires or sets of wires of various lengths and sizes inside the piano (Figure 312). Each key operates a wooden hammer covered with felt. You make the strings vibrate by hitting them with the felt-covered hammers.

Other stringed instruments, such as violins, cellos, and bass violins, work differently. You make the strings vibrate by drawing bows across them. The bow that is used with these instruments holds a strand of tightly stretched horsehairs. Before playing, the hairs are rubbed with rosin. Then, as the hairs are drawn across the string, the peculiar friction of the rosin makes the string vibrate in the best way.



musical instruments. (Galloway photo)

Notice that the strings of stringed instruments are attached to large boards or to box-like parts with openings in them. A simple instrument will help you understand the value of these parts.

Experiment 27. *What Effect Do Sounding-Boards and Air Spaces Have on the Sound from Vibrating Bodies That Touch Them?* Obtain a thin board (the top of a cigar box will do) and a good cigar box. Fasten the lid of the cigar box tightly shut with brads and glue. Bore two clean one-inch holes in each end of the box. (*a*) Strike a tuning-fork with a rubber hammer and notice the loudness of the sound. (*b*) Strike the tuning-fork again and place the end of the "handle" against the middle of the thin board held by

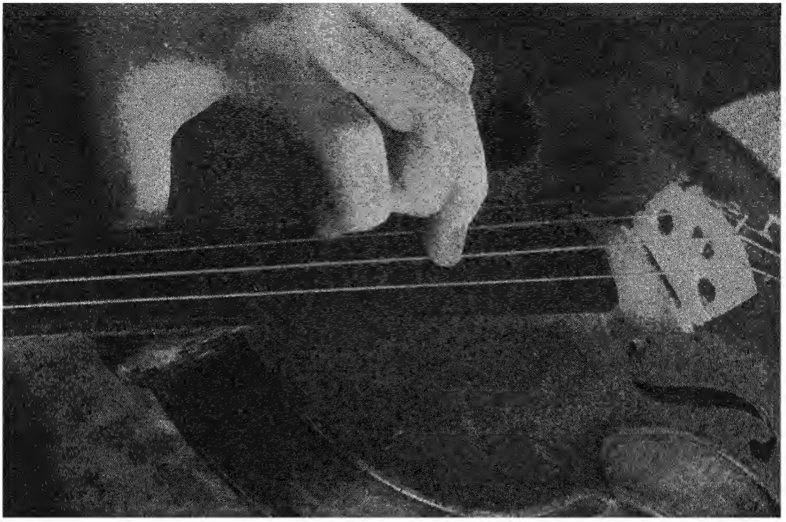


FIG. 320. The bridge and the body of the violin increase the volume of the sound and greatly affect its quality. (Kaufman-Fabry photo)

someone else. What effect does the board have on the loudness of the sound? (*c*) Repeat the experiment and hold the handle of the vibrating fork against the top of the cigar box you have prepared. What is the result?

From your experiment you can see that the surfaces and air spaces connected with a vibrating body can increase the sound very greatly. They are said to *reënforce* the sound. Often they do this because the vibrating body passes its vibrations along to a larger surface. This larger surface can cause stronger vibrations in the air than can a smaller vibrating string. In an enclosed air space of the correct size and shape, the vibrations carried through wood or metal set the air vibrating very strongly. Waves from this vibrating air pass out through the openings and increase the loudness, or volume, of the sound.

By affecting the overtones these sounding surfaces and air spaces also change the quality of the sound an instrument can produce. The difference between a poor violin and a good one is the result of the differences in the wooden parts and the air spaces.

FIG. 321. The brass sextette of the Proviso (Ill.) Township High School with a marimba. From left to right the brass instruments are: French horn, alto horn, two trumpets, trombone, and tuba. (Photo from *Music Educators*, Chicago)

Pianos have a *sounding-board* behind the strings. This sounding-board reënforces the sounds that are made when the hammers strike the strings. The tightly stretched skin covering on the "head" of a banjo helps give the instrument the "snappy" sound that people like. The open space in the body of a guitar lets the air in the guitar vibrate in response to the strings. All these devices help stringed instruments make their own kinds of music.

HOW DO WIND INSTRUMENTS WORK? Did you ever watch someone play a saxophone, a trumpet, or a trombone? Perhaps you play one of these instruments. What happens to make these instruments produce sounds? An experiment will help you find out for yourself.

EXPERIMENT 28. *How Do Wind Instruments Produce Sound?* (*a*) Get eight long test-tubes that have small diameters. "Tune" the test-tubes by pouring different amounts of water into them (Figure 322). Hold the ends of the tubes at right angles to your lips and blow across them. Can you feel the vibrations as the air in the tubes vibrates to produce sounds? Which tube gives

FIG. 322. Apparatus to show how the length of an air column affects the tone it produces

the highest sound? Which gives the lowest? Try to tune the tubes to play a scale by regulating the amounts of water in them.

b) Remove the metal guard-plate from an harmonica and have a classmate play it. What parts vibrate to produce sound?

c) If anyone in your class is a bugler, have him bring a bugle to school. Watch him play it. Clean the mouthpiece carefully and try to play it yourself. What happens to your lips as you make the bugle sound?

When you blew across the glass tubes, you produced sounds by making the air in the tubes vibrate. The vibrating air in a closed space is called an *air column*. You found that the short tubes made high-pitched sounds and that the long tubes made low-pitched sounds. In wind instruments the pitch is often changed by changing the length of the air column. In trombones this is done by a sliding part that moves back and forth. In other wind instruments, a cornet for example, valves are used to change the length of the air column. In the trumpet, the cornet, the trombone, the French horn, and the tuba the

FIG. 323. Opening and closing the valves of the various wind instruments change the length of the air column within and thus change the tone. (Ewing Galloway photo)

air column is made to vibrate by means of the lips. If you have ever tried to play either of these, you probably found that at first it "tickled" your lips.

Like strings, the air columns in wind instruments can vibrate in parts and give out overtones. By changing the tightness of his lips a bugler or a trumpet player can control the fractions in which the air column vibrates and thus cause the same air column to give out a number of different "notes."

When you watched the harmonica play, you saw different lengths of metal, called *reeds*, vibrate to produce different sounds. Clarinets, saxophones, bassoons, and oboes have wooden reeds to produce their sounds. The saxophone and the clarinet have one reed, while the bassoon and the oboe have two reeds. The length of the air column is changed by opening and closing valves in the long tube-like part of the instrument.

In all of this discussion of wind instruments you must remember that the size of the instrument, the number of coils, the material the instrument is made of, and the material the reed is made of (if it is a reed instrument) are of great importance in producing the particular sound quality for which each instrument is noted.

The next time you see an orchestra, try to think how the sound is produced in each instrument, and try to ob-

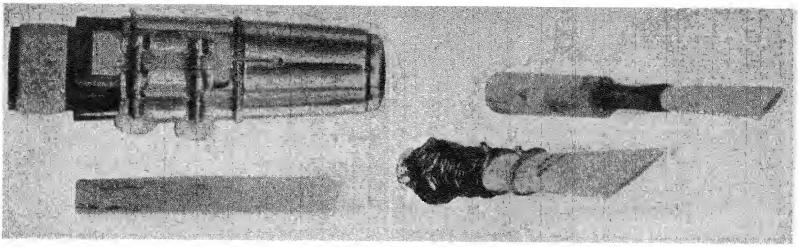


FIG. 324. A mouthpiece and reeds of some wood-wind instruments. The clarinet and saxophone have a mouthpiece with a single reed as shown at the left. The bassoon, oboe, and English horn have a double reed, as shown at the right. (Photo by courtesy Tonk Brothers)

serve how the sound is regulated in each case. You will not at first be able to do these things for every instrument, but you will learn more about them as you continue trying. In this way you will add greatly to your understanding of instruments and your enjoyment of music.

Self-Testing Exercises

1. Make a list of the musical instruments that are shown in Figure 317. Divide them into three groups: percussion, stringed, and wind instruments.

2. Complete the table below.

Instrument	Part That Produces Sound	How Pitch of Sound Is Controlled
Piano	*Vibrating strings*	*Strings of different lengths and of different diameters produce sounds of different pitch.*
Harp		
Violin		
Saxophone		
Trombone		
Harmonica		
Kettle drum		

Problems to Solve

1. Look in some reference book and find what instruments are used in a large orchestra. Find out how these instruments are placed to give the best effect.

2. Examine the reeds of a clarinet and a saxophone, if possible, to see how they are different. Why do these instruments produce different kinds of sounds?

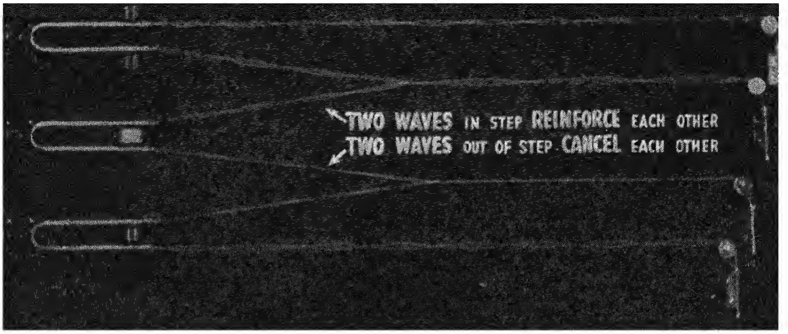


FIG. 325. These cords are being made to vibrate by tuning forks that are vibrated by electromagnets. The two top forks are vibrating with each other; therefore the cords that join them pass their vibrations on to the single cord, which vibrates very strongly. The two bottom forks are vibrating in opposite directions from each other; therefore the vibrations of the cords attached to them stop at the point where they form the single cord. (Photo from Museum of Science and Industry, Chicago, by courtesy of *Educational Music Magazine*)

Problem 4:
HOW DO WE HEAR?

WHAT ARE SYMPATHETIC VIBRATIONS? In Problem 1 you learned how sounds are sent out by our voices. Have you ever wondered how we hear these sounds? Scientists are not yet sure how our ears work, but they learned some important things. To understand the facts about your ears, you should know something about *sympathetic vibrations*. This will help you understand a number of the effects of sound in addition to hearing.

Perhaps you have noticed that when someone is playing a piano, a vase or other light object on the piano may rattle. Did you ever hear someone say that if you held a large seashell to your ear, you could hear the roaring of the sea? Of course you did not hear the roaring of the sea, but you did hear faint roaring noises. What causes the vase to vibrate, and why does the seashell sound when you hold it to your ear? Before you try to answer these questions, do the following experiment to see if you can produce sounds in a similar manner.

EXPERIMENT 29. *How Can One Sounding Body Produce Sound in Another Body?* (*a*) Get two cigar boxes that are the same size and remove one end from each box. Close the tops and fasten them with tiny nails. Place the boxes about six inches apart with their open ends facing each other. Get two tuning-forks that are alike (that produce the same number of vibrations per second—256 for example). Have a classmate hold the base of one of the forks against the top of one of the cigar boxes.

Strike the other tuning-fork and hold it against the top of the other cigar box. Then stop the tuning-fork from vibrating by closing your fingers about the prongs. Listen carefully to the tuning-fork that your classmate is holding. How do you explain the results?

b) Repeat the experiment, using two tuning-forks that do not give the same number of vibrations per second (for example, 256 and 320). Listen carefully to the tuning-fork that is not struck. Does it sound?

In part *a* of the experiment the tuning-fork you struck sent out vibrations into the air. As the vibrating particles of the first sound wave reached the still fork, they made it move back and forth a little in response to their motion. The second wave gave the fork a little push just as it started on its second vibration. Each sound wave thus made the second fork vibrate a little more. The second fork then gave out sound because it was tuned to the first fork; that is, it could give out the same number of vibrations per second as the first fork, and the rate of its vibrations was the same as the rate at which the sound waves struck it.

In part *b* of the experiment the still fork did not sound in response to the fork you struck. The still fork could not vibrate in time with the waves that struck it. In other words, the still fork was "out of tune" with the fork you

struck. As a result, it gave out no sound. Do you see that sound waves make a body vibrate if the body can give out the same number of vibrations per second as the sound waves that reach it? When sound waves from one body make another body vibrate, the two objects are said to be in *sympathetic vibration.*

Sympathetic vibrations occur very often, but most of us pay little attention to them. Hold down the loud pedal of a piano and sing a loud "O" sound. You will hear sympathetic vibrations from the string of the piano that is in tune with the note you sang. Watch the radio when it is playing loudly. Some small glass or metal object on the radio may vibrate in response to certain sounds. Scientists tell us that sometimes very fragile glass vases have been broken by means of sympathetic vibrations. Can you now tell why the seashell mentioned on page 356 gives out a faint roaring noise when you hold it tightly against your ear?

Self-Testing Exercises

1. Explain in your own words what causes sympathetic vibrations.

2. Give examples of your own to illustrate what is meant by sympathetic vibrations.

WHAT IS THE STRUCTURE OF THE EAR? Three things are necessary for us to hear a sound. First, as you know, vibrations must be produced by some rapidly moving object. Second, some material must carry the sound waves from the vibrating object to us. Third, there must be something to receive these vibrations and interpret them as sounds. Our ears are the parts of our bodies that do this last thing. Figure 326 shows that an ear consists of three parts—the *outer ear*, the *middle ear*, and the *inner ear*. The outer ear is made up of the shell of flexible carti-

lage and skin that is attached to each side of the head. It includes also the opening, or *canal*, that leads into the head. A thin membrane, the *ear drum*, is stretched across the inner end of the canal. The drum is the partition between the outer ear and the middle ear.

In the middle ear are three tiny bones fastened together by ligaments. The first of the bones touches the drum. The third bone is in contact with the inner ear. The inner ear consists of a device, the *cochlea*, which is shaped like a snail's shell and is filled with a liquid. The cochlea has a spiral membrane that is fastened to the central part, much as the threads are coiled about a screw. This membrane is made of a great many crosswise strands of varying lengths. The *auditory* (hearing) *nerve* leads out from the cross strands to carry the impulses to the brain.

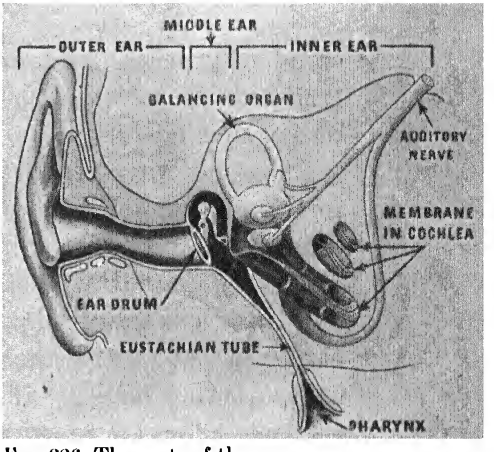


FIG. 326. The parts of the ear

HOW DOES THE EAR WORK? Now that we know how the ear is made, let us follow a sound wave to see how each of the parts of the ear helps us hear. The outside part of the ear is really a "megaphone in reverse"; that is, it collects sound waves and leads them into the canal. Get a megaphone and hold the mouthpiece to your ear. You will be surprised at the results, for even in a room so still that you can "hear a pin fall," you can hear many noises. Sounds too faint and scattered to be noticed can be heard easily with a megaphone in this position. Now you under-

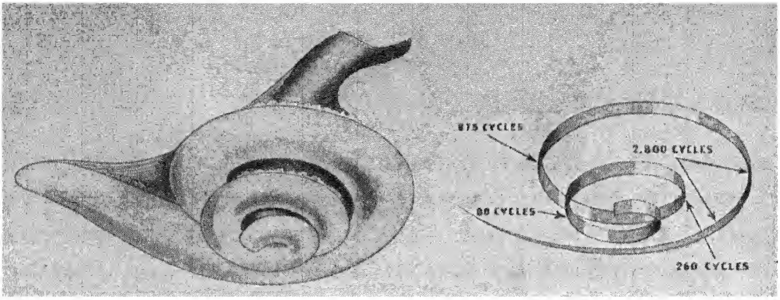


FIG. 327. At the left is a drawing of the outside of the cochlea. At the right is shown the membrane that enables us to tell high sounds from low sounds. The numbers show the parts of the membrane that vibrate in response to sounds of those frequencies. *Cycles* mean the number of vibrations per second.

stand why people who are partly deaf used to have ear trumpets. However, as you will learn later, another kind of device is now used by people who are hard of hearing.

As sound waves reach the middle ear, the back-and-forth movements of the air particles cause the drum to move back and forth (see page 333). The vibrating drum makes the three tiny bones vibrate, and these bones carry the vibrations to the liquid of the cochlea. You learned earlier in this part of the unit that a vibrating body can cause another body to vibrate in sympathy with itself if the two bodies are in tune (Experiment 29).

One theory of how we hear is that the vibrations of the liquid in the inner ear cause sympathetic vibrations in the spiral membrane of the cochlea. For example, the long strands respond to low-pitched sounds, and the short strands respond to high-pitched sounds (Figure 327). Tiny nerve fibers are connected all along the spiral membrane. The part of the membrane that is vibrating sends nerve messages to the brain. Thus we can tell the kind of sound we are hearing. In this way we can hear sounds that range from 16 vibrations per second to 20,000 per second.

Think how delicate these hearing organs must be. The tiniest bit of energy is changed into air vibrations by

someone's vocal cords, by a ticking clock, by a falling spoon. These vibrations spread out in all directions until only a thousandth or a millionth part of the energy reaches our ears. Yet we recognize the sound and can usually tell which direction it came from.

There are two other interesting parts of the inner ear. Figure 326 shows a peculiar part known as the *balancing organ.* This organ does just what its name tells us; it helps us keep our balance. Probably when you ride rapidly on a merry-go-round, you feel dizzy. This is because the liquid in this balancing organ is disturbed. Also, the diagram shows a slender tube from the back of the mouth to the middle ear. This is known as the *Eustachian tube.*

Did you ever ride very swiftly up several stories in an elevator or up a steep mountain road? Probably you felt a peculiar sensation in your ears. You heard a slight popping noise, and the pressure in your ears felt too great. Someone may have told you to swallow several times to relieve this. What really happened was that the air-pressure very rapidly became less on the outside of your ear drums. This left the pressure much greater on the inside of your ear drums. When you swallowed, some air moved out through your Eustachian tube to let the pressure become the same on the two sides of your ear drums.

People who are "hard of hearing" no longer need to use ear trumpets. Modern hearing aids have a "microphone," "radio set," and a "loudspeaker," or receiver. One kind is so fixed that the receiver can be placed in the opening of the outer ear to strengthen or amplify the vibrations that are received. Another kind is made so that the receiver is clamped just back of the ear. The vibrations that are received by this instrument are transmitted through the bones of the head to the liquid of the inner ear.

FIG. 328. A hearing device that helps carry the sound waves directly to the ear drum. It is connected with a small electric cell. (Sonotone Corp. photos)

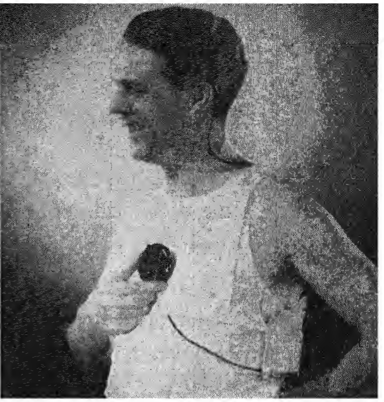


FIG. 329. A hearing device that transmits the sound waves to the bones of the head. Notice the little microphone and the bag of batteries beneath the arm.

You will understand better how the last-named instrument works if you will stop both ears tightly and hold a watch between your teeth. You can hear the watch quite plainly. Its vibrations are transmitted through your teeth to the bones of your head and then to the liquid of the inner ear. From there the auditory nerve carries the impulses to the brain, where they are registered as sound. Of course, the person who is to use these hearing aids must try them to see which type is best suited to his needs.

Since it is very important for us to hear well, let us mention a few ways of caring for the delicate organs with which we hear. A thick waxy substance is secreted in the canals to protect them. This wax should never be removed with a small sharp stick or other sharp instrument.

You should be careful not to swim in water that might have germs in it, since some of them might easily get into the canals of your ears and cause infections. Before you do much diving, you should have a doctor examine your ears to see that they are in good condition, as sudden changes of pressure affect the drums. The doctor may advise you to wear rubber "ear stoppers" for protection.

You should avoid letting anyone shout loudly in your ears. The sudden vibrations might push the drums in too far and injure them. Also avoid "blowing your nose" too hard when you have a cold. The pressure may push bacteria up the Eustachian tube into the middle ear. Remember to consult a doctor at once when anything is wrong with your ears.

Self-Testing Exercises

1. Compare the crosswise strands of the spiral membrane of the cochlea to the strings of a piano. How are they alike? How are they different?
2. Why do you think it was necessary for you to learn about sympathetic vibrations before you could learn how we hear?
3. Tell what happens in hearing sounds from the time the sound waves reach your ears until the brain "registers" the sound.
4. What is the Eustachian tube for?
5. Make a list of the ways by which you can take care of your hearing.

Problems to Solve

1. Find out how your school doctor tests your hearing when he gives you a physical examination.
2. Look in some good reference book to learn more about how the balancing organs work.

Problem 5:
HOW ARE SOUND WAVES REPRODUCED?

HOW ARE SOUNDS RECORDED? Perhaps you have enjoyed playing phonograph records and have wondered how they produce sounds. The phonograph is a remarkable invention, yet we can easily learn the main things about how it works. Let us first find how sound is recorded on flat discs of the kind that can be bought at any music store.

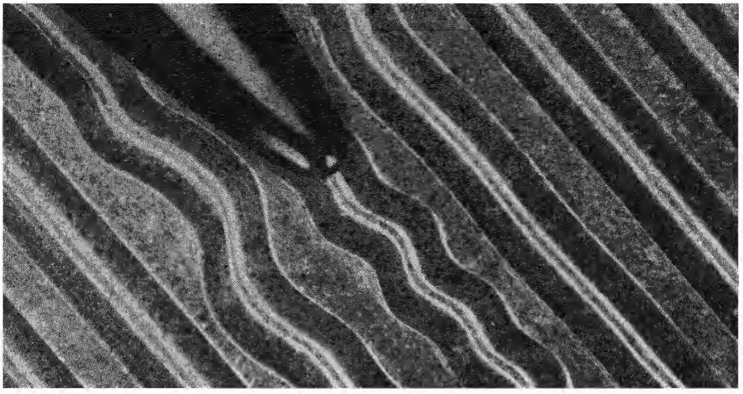


FIG. 330. Phonograph needle and record grooves as they look when highly magnified (R.C.A. photo)

Suppose a singer is making a record. What happens during the process? You have learned earlier in the unit that sound waves make objects vibrate when they strike them. The singer sings into a recorder that has across the mouthpiece a thin piece of material called a *diaphragm.* The sound waves caused by the singer's voice make the diaphragm vibrate. When the sound is loud, the diaphragm moves in and out for a great distance. When the sound is low, the diaphragm moves in and out only a slight distance.

In older types of recording machines a sharp needle was pivoted to the center of the diaphragm. This needle rested on a soft wax plate that was rotating. The vibrations were carried from the diaphragm to the needle. As the diaphragm vibrated, the needle was moved slightly from side to side as it went around the wax plate. This cut a curved groove into the plate. This groove was really a record of the sound waves that were produced by the singer. Examine a phonograph record with a strong magnifying-glass to see what the grooves are like (Figure 330).

Today phonograph records are made by an improved process, as you will learn later. But *Dictaphones* use the

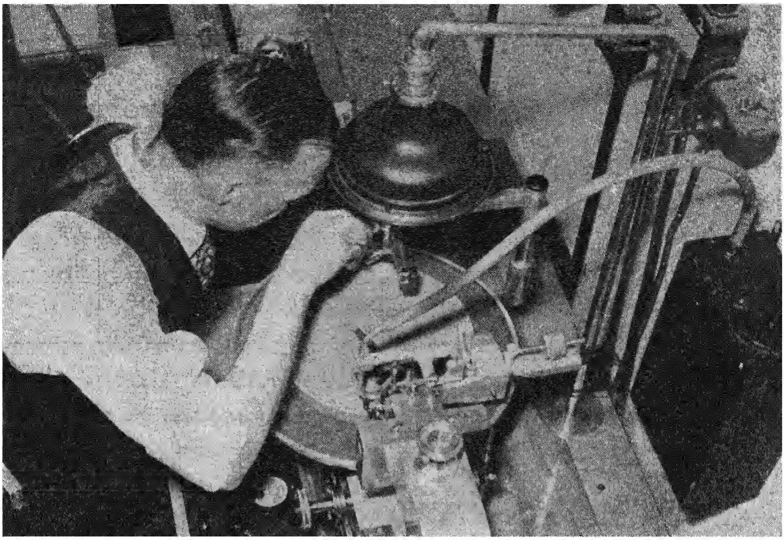


FIG. 331. This man is cutting the first wax disc from which the master phonograph records will be made. (R.C.A. photo)

method of recording that has just been described. A person dictating a letter speaks into a machine that records the vibrations of his voice on a revolving wax disc or cylinder. When the secretary wishes to type the letter, she plays the record of the voice, much as we play records on a phonograph. As the speaker's voice is reproduced, the secretary types the words, and the Dictaphone has done its work.

In the modern method of making phonograph records, the performer sings or speaks into a machine with a diaphragm like the one you have just read about. In this method, however, an electric current is used to transmit the vibrations to a recording needle. The needle cuts a wavy groove in a soft wax plate. This process is known as *electrical recording*. It makes a better record of very high and very low notes than the older method. The older machines could not make a record of very high and very low notes that would sound natural when it was played. In addition to making more natural records, elec-

trical recording improves the quality of sounds that can be reproduced. In other words, it makes a singer's voice, spoken words, and music from instruments sound almost exactly as they sound when we hear them directly from a person or from musical instruments.

By means of electricity the soft wax record is duplicated in copper. Later you will learn more about this process, known as electroplating. A commercial record of the kind you buy in music stores is made by pressing the copper plate against a smooth disc with a force of several tons. In this way the disc is made into a record that is ready to be played on your phonograph.

HOW ARE SOUNDS REPRODUCED IN PHONOGRAPHS? Now let us see how the phonograph reproduces sound from these records. An experiment will help you understand this better.

EXPERIMENT 30. *How Does a Phonograph Record Produce Vibrations?* If you can get a phonograph, put a record on the turn-table and start it moving. As the record turns, hold a long thin sewing-machine needle between your fingers. Place the point of the needle on the rough part of the record. Can you feel the needle vibrate slightly as it follows the groove? Hold your ear close to the needle. Can you hear a faint sound?

Hold the needle between your teeth with your lips apart. Place the point of the needle in the groove. Can you feel the vibrations with the needle between your teeth? Can you hear the sound more plainly? Hold the needle in the fingers with a small card touching the needle. The card acts like a diaphragm.

During the experiment you probably observed that reproducing sound from a record is just the reverse of the recording process. To reproduce sound, a diaphragm is used (Figure 332). The diaphragm has a pivoted needle connected to its center. As the record is rotated, the needle

is placed in the groove near the edge of the record. Remember that the groove is wavy; it corresponds to the vibrations of the sounds that made it. The needle vibrates from side to side as it follows the groove.

In mechanical phonographs the vibrations from the needle are carried directly to the diaphragm, which changes them into sound waves. The sound waves are then carried through a tube and sent out through a loudspeaker into the air. In electrical phonographs the vibrations are carried by electric current to tubes similar to those in your radio. These tubes amplify (strengthen) the electrical vibrations. The amplified vibrations go to a loudspeaker, where they are changed to sound waves by an electromagnet and a diaphragm.

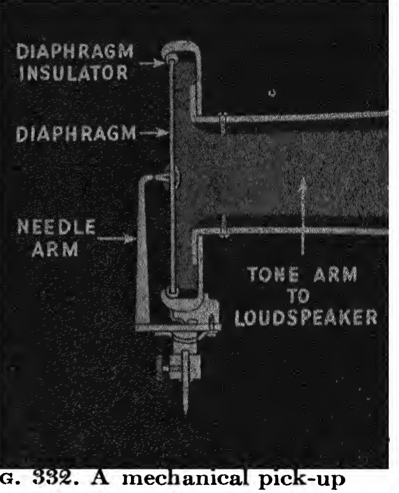


FIG. 332. A mechanical pick-up

Self-Testing Exercises

1. Tell in your own words how a phonograph record is made.
2. Explain why the groove in a record is crooked.
3. What is meant by electrical recording? What are some of its advantages?
4. Tell how a phonograph record makes sound.

Problems to Solve

1. Read in some good reference to learn more about how records are made. Make a report of your findings to the class.
2. Find out how *hill-and-dale* recording is done.
3. Read the story of Edison and the first phonograph.

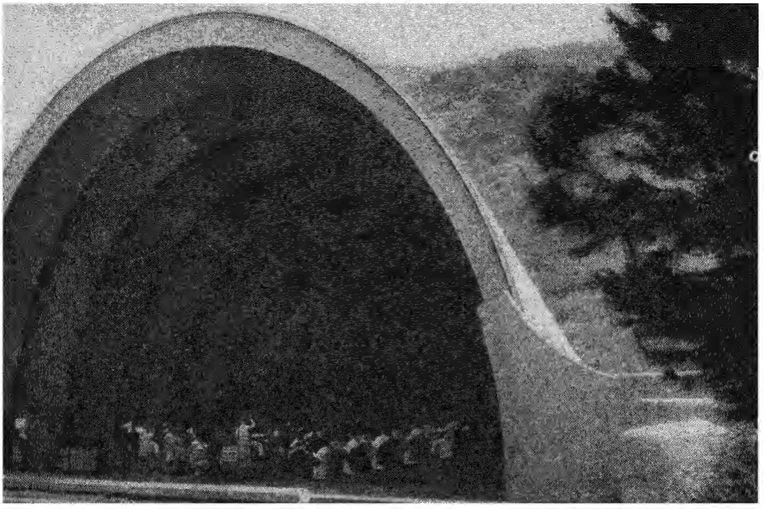


FIG. 333. The band shell at Hollywood Bowl, California (Burton Holmes photo from Ewing Galloway)

Problem 6:

HOW DO WE CONTROL SOUND?

HOW ARE SOUNDS MADE LOUDER? Have you ever been awakened by the noise of a train or a truck as it passed near you? Have you ever tried to listen to music or to a speaker in an auditorium which made the sounds seem "blurred"? One of man's big problems today is to control sound. Thus far in the unit you have studied how sound is controlled in musical instruments and in sound reproducing machines, such as phonographs. In this problem you will learn of some other ways in which man uses his knowledge of sound.

Megaphones are used to direct sound waves in the direction we wish them to go. Band shells (Figure 333) are another way in which sounds are made louder. When you listen to a band or an orchestra playing in a band shell, some parts of the sound waves go directly to you. Other parts of these waves go back against the curved walls of the band shell and are reflected back to you. In this way sound waves can be directed toward the listeners instead of being scattered in all directions. If you have ever

listened to a band play in the open, you will know how hard it was to hear the music when you were some distance away. Many auditoriums use some kind of reflecting device back of the speaker to make his voice easier to hear.

Still another way of making sounds louder is by means of *resonators* and sounding-boards, as in the musical instruments of Problem 4. In Experiment 29 you used cigar boxes as resonators to make the faint sounds of the tuning-forks louder. This resonance is greater when the air column is the right size to vibrate in sympathy with the vibrating object. The electric door chime in Figure 334 owes its pleasant singing tone to resonance. When the door button is pushed, an electromagnet makes a hammer rise and strike the bar on the under side. The air space inside the tube is the right size to vibrate in sympathy with the bar. In this way the sound of the vibrating bar is reënforced, and a pleasant singing tone is heard.

HOW ARE ECHOES PREVENTED? Another problem in constructing auditoriums and other buildings is preventing echoes. Have you ever played out-of-doors some distance from the walls of a large building or in a meadow some distance from a cliff? If you have, you probably noticed that shortly after you call (on a still day) you can

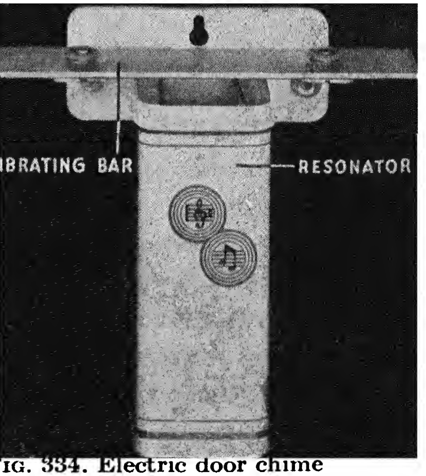


FIG. 334. Electric door chime

hear your own voice repeating the same call. What causes echoes?

When sound waves strike a large surface, such as a wall of the face of a cliff, they are reflected back to you. Scientists have found that you must be at least fifty-five feet away from a building or cliff to hear echoes clearly. If you are nearer, the sound is reflected to you so quickly that you do not notice the difference between the original sound and the reflected sound.

Echoes are sometimes very annoying indoors. Most rooms are shorter than fifty-five feet; so we do not hear distinct echoes in them. But when you clap your hands or speak in an unfurnished room, you can hear peculiar ringing sounds that are caused by the reflection of sound from wall to wall. Sometimes auditoriums are just the right length for sound to travel from the speaker's voice to the back wall and return in time to overlap his words. This makes the speaker's voice sound blurred and makes it hard for the audience to understand him.

Scientists are learning how to design rooms that do not echo badly. They do this by planning the shape and size of the rooms with great care. In many cases, however, it is found that echoes must be controlled after a building has been erected. Walls that are covered with smooth, hard plaster make excellent sound reflectors. In such cases the echoes can often be overcome by hanging heavy curtains at the back of the auditorium to absorb the sound waves that reach it. Carpets and upholstered seats also help keep down the reflection of sound waves.

Sometimes the walls and ceilings (Figure 335) of large halls are covered with a special kind of plaster that has a soft, rough surface which absorbs sound waves instead of reflecting them. Composition wall-boards that have

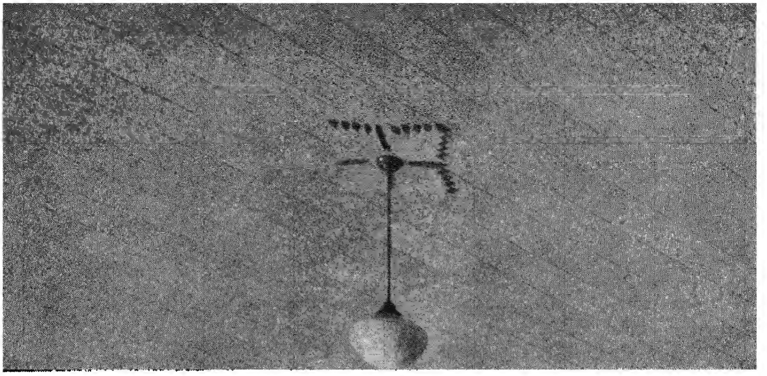


FIG. 335. Sound-insulating material on the ceiling of the high-school auditorium at Alexandria, Virginia (U. S. Gypsum Co. photo)

rough, porous surfaces are used for the same purpose. Look in your school auditorium, in restaurants, and in theaters to see whether you can find some of these materials in actual use.

Self-Testing Exercises

1. What causes an echo?
2. Why are echoes in auditoriums undesirable?
3. How can echoes in rooms be reduced?
4. How does a megaphone help control sound?

Problems to Solve

1. The next time you hear an echo, try to find how far the reflecting surface is from the source of sound.

2. Find what is meant by *acoustical engineering*. Report your findings to your class.

HOW IS NOISE REDUCED? Noise cuts down our efficiency when we are working, disturbs us when we are asleep, and causes unhealthy nervous tension. Noise can be lessened by reducing the number of causes of sound. Some cities, for example, have reduced noise by teaching automobile drivers to use their horns only when necessary, and good drivers do not need to use their horns very often. Rubber tires on autos and trucks, rubber heels, rubber shoes for milkmen and their horses, and

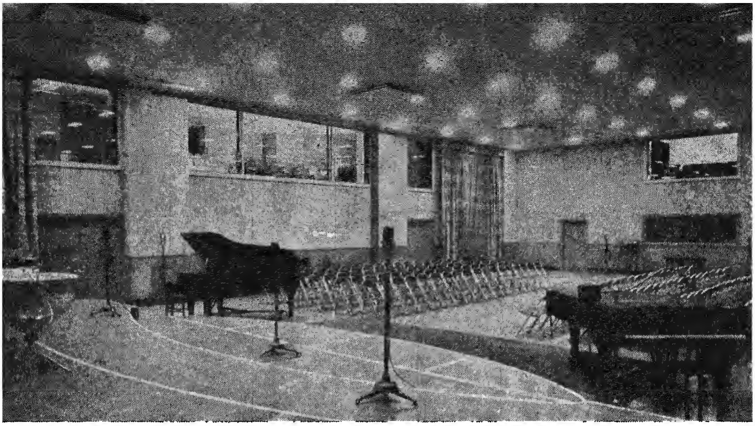


FIG. 336. One of the orchestral studios of a radio broadcasting station. Such rooms must be very carefully planned by acoustical engineers to avoid echoes and reverberations that would be caught by the sensitive microphones. (N.B.C. photo)

heavy carpets on floors all prevent the vibrations that cause sound.

A second important way to reduce noise is to absorb the sound vibrations after they have been started. Mufflers on automobile exhaust pipes absorb much of the sound of the motor's explosions. And you have already learned that rough surfaces and cloth coverings for walls and floors absorb sound. Very often, too, sound vibrations can be prevented from passing through walls and through metal or wood to surfaces that make them louder. Porous and flexible materials such as rubber, felt, and rock wool do not transmit sound waves as air, wood, and steel do. They are therefore called *sound insulators*.

Sound insulation is used in many places. Typewriters are placed on felt or rubber pads to keep their vibrations from passing to the tables. Automobile and electric motors are mounted on rubber blocks. Felt strips are put between parts of automobile bodies. The walls of broadcasting studios and apartment buildings are filled with rock wool or other sound-insulating materials. Can you find other uses for these materials?

Self-Testing Exercises

1. Why is noise undesirable?

2. State two important ways of reducing noise. Give three examples of each way.

3. What is a sound-insulating material? Give some examples of the use of such materials.

Problems to Solve

1. Find out how broadcasting studios are sound-insulated.

2. If possible, get some samples of sound-insulating materials and make an exhibit for your class.

3. Find out how *fathometers* show the depth of the ocean.

4. Explain why the alarm clock shown in Figure 299 was placed on a thick pad of cotton.

LOOKING BACK AT UNIT 6

1. Copy the headings of all the problems and sub-problems of the unit. Under each one write the main ideas that are needed to give a good answer to that problem.

2. Look over the answers you made for the Introductory Exercises on page 314. What changes would you make in answering these exercises now? Write these changes on a sheet of paper and add them to your original answers.

3. Show that you know the meanings of the following words by using them in sentences or in other ways:

acoustical engineer	*quality*	*reed*
auditory nerve	*noise*	*resonator*
cochlea	*overtone*	*sound waves*
echo	*percussion instruments*	*sympathetic vibration*
larynx	*pitch*	*vocal cords*

ADDITIONAL EXERCISES

1. What vibrates to cause sound in the pipes of a pipe organ?

2. When you are sitting at the back of a large auditorium, you hear the low notes and the high notes of an orchestra at the same time. From this experience, do you think that pitch affects the speed of sound? Explain.

3. When you are in a noisy room, why do you cup your hands behind your ears when the speaker is not talking loudly? Why do you sometimes cup your hands about your mouth before you call to a person some distance from you?

4. If you were playing a phonograph and speeded up the number of revolutions of the record, what would be the effect on the music it was producing? Explain why.

5. Speaking-tubes are long tubes with funnel-shaped ends. Voices can be heard long distances through walls by using such tubes. Explain why they are successful.

6. Make a string telephone. To do this, fasten the end of a long, strong string or a small wire tightly in the bottom of a medium or large-sized tin can. In the same way fasten the other end in the bottom of another tin can. Stretch the string or wire tight and speak into one tin can while a friend holds the other can to his ear. Does sound travel along the string or wire?

7. Construct a musical instrument with strings, a board, and a cigar box.

8. Read about Helmholtz and some of the things he discovered about sound.

9. How are sounds used to study the structure of rocks below the surface of the earth? This is called *geophysical prospecting*. Look in reference books under this name and in articles on petroleum.

10. Find out about the "Doppler effect." First hear it for yourself. Stand by a road while automobiles are going. Notice whether the pitch of the sounds they make becomes higher or lower as they go by you. Then look in physics books to find the cause for the change in pitch.

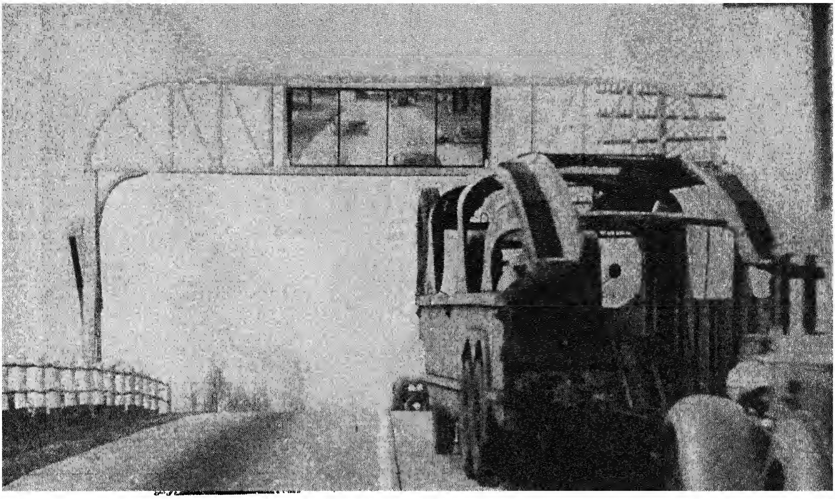


FIG. 338. Perhaps you live in Pennsylvania, near the place where this new traffic invention was first tried out. Do you know how it works? (Photo by Mieth from *Life*)

LOOKING AHEAD TO UNIT 7

WHILE THIS book was being written, a very interesting invention was made to help avoid automobile accidents on hills. The invention looked like a bridge across the highway at the top of the hill and about twenty-five or thirty feet above the pavement. But the purpose of this structure was to act as a support for huge sheets of glass. As you started up the hill, you looked up into the glass, and you could see any automobiles that might be on the other side of the hill.

Perhaps you think that this was made possible by mirrors, but you are mistaken. The glass into which you looked was clear glass. You were looking through it, and you were actually seeing over the top of the hill and down the other side. Do you have any idea how this sheet of glass could make it possible for you to see in a way that you know you cannot ordinarily see? What did the glass do to show you the road on the other side of the hill? You will be able to explain this interesting invention when you have found out in this unit how light acts.

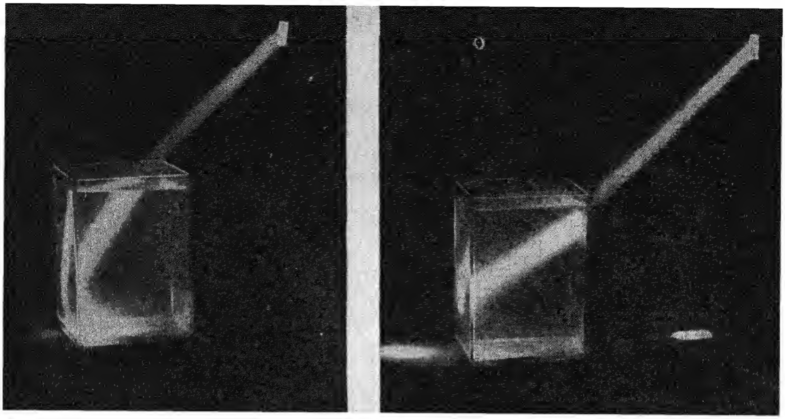


FIG. 339. Why does this beam of light do such strange things when it enters the water in the jar? When you have studied this unit, you will be able to explain these pictures.

If you have a ruler on your desk, look at it. You will see that it looks perfectly straight. But there is a way to make the ruler look as if it were bent. Just hold it in a slanting position in water and look at it from the side. Of course, putting the ruler in water does not bend it. It just looks as if it were bent. But why does it look this way? If you hold the ruler straight up in the water and look down at the end in the water, you will see that it looks much shorter. Why do you suppose it looks bent when held in a slanting position and shorter when held upright?

Did you ever wish that you had eyes in the back of your head, so that you could see what was going on behind you? Perhaps you think that your teacher has. There is, of course, no way to look behind you without turning your head. But there is a way to see behind you. If you have not guessed already what that way is, you will understand when we say that all you need is a mirror. You probably look at yourself in a mirror at least once a day. If you are a girl, you may look more often. A mirror is such a common thing that you have probably never wondered why you could see yourself in it. But why can you? You cannot see yourself if you face a piece of wood

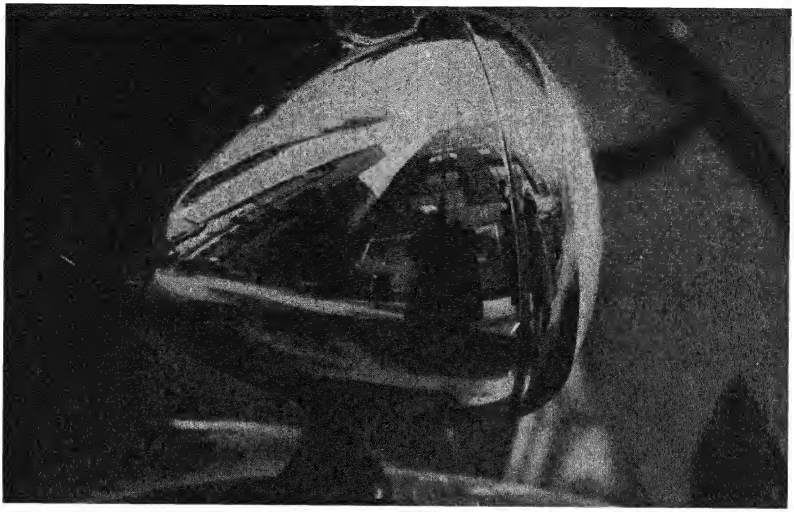


FIG. 340. You have probably often seen the strange shapes that buildings and people take when they are seen in curved mirrors, as shown in this polished automobile lamp. (Photo from *The Texaco Star*)

or a piece of paper. Perhaps you think the answer is that you can see yourself in the mirror because it is shiny. But why can you see yourself in shiny surfaces and not in other kinds of surfaces?

Carnival companies sometimes have strange mirrors. If you look at yourself in one of these mirrors, you may look short and fat; in another mirror you may look tall and thin. You know that you cannot be short and tall at the same time. As a matter of fact, neither one of these mirrors is telling the truth. Can you explain how they can change your appearance?

These questions are only a few of those that can be asked about the way in which light behaves. You can see already that people who say, "I believe what I see," had better be careful. What they think they see is often much different from the real facts. It is an actual fact that a short girl will look shorter and fatter if she wears a dress with stripes running around the body or with a large plaid pattern. She will look taller and slimmer in a dress with

vertical stripes. It is also a fact, as you know, that a magnifying-glass will make objects look larger, and a telescope will make distant objects appear much nearer. Colors of objects do not always appear the same, either. In the sunlight they do not look the same as they do in the light of an electric lamp.

In this unit we will try to find out the reasons for some of the strange ways you see things. When you know how light travels and how it behaves under certain conditions, you will be able to understand the experiments and the facts you have just read about.

Problem 1:
HOW DOES LIGHT BEHAVE?

WHY ARE OBJECTS VISIBLE? When you go into a totally dark room, what do you see? Nothing, of course. Then you turn on a switch, and, presto, your invisible surroundings become visible chairs, tables, rugs, and pictures. They were there all the time, but you could not see them. Just a turn of a switch that lighted a small electric lamp brought about this change. The lamp, however, has the power of sending out light. When it sends out light, it becomes visible itself. And its light helps you see other things that do not themselves give out light.

We are so used to having light whenever we want it that we seldom think how different life would be without it. We use our eyes for practically everything we do. Without light, however, we would have no use for eyes. Curiously enough, certain people of long ago thought that they could see things because something traveled from their eyes to the object. We now know, however, that we see because light travels from the object to our eyes.

While it is true that we can see only objects that send light to our eyes, there are very few objects that have the

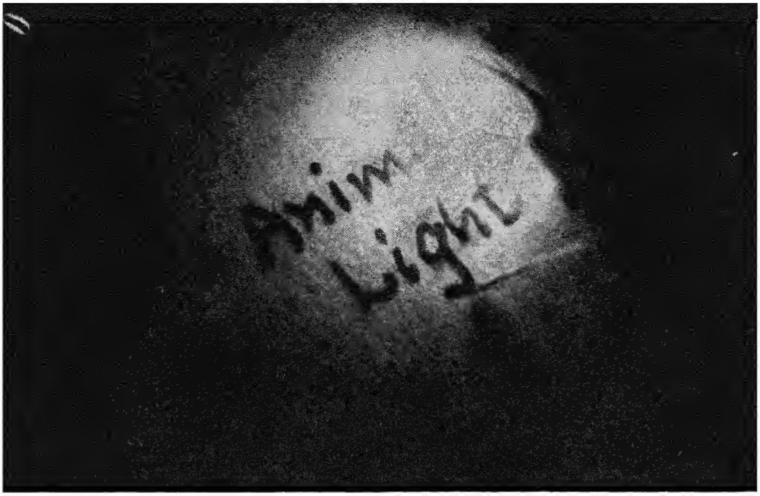


FIG. 341. This picture was taken by flashlight; and what do you suppose the flashlight was? It was a lightning-bug. You can see the dim outlines of parts of its body. (Photo by Dr. Ralph Buchsbaum from his *Animals Without Backbones*)

power of producing and sending out light. The sun, as you know, is one of these. From far out in space, other suns, the stars, send us their dim light. Metals give off light if they are heated hot enough. In our electric lamps a fine wire is heated so hot that it gives out light. When materials burn, the materials in the flame are heated and become *luminous;* that is, they give out light. Kerosene, gasoline, and gas lights are possible because of this fact. On a summer evening we can see the lightning-bug, or firefly, turn its little glow of light on and off. Deep down in the ocean, where no light from the sun can reach, are deep-sea fish that light up the depths in somewhat the same manner as the lightning-bug. These animals are almost the only sources of light that nature provides.

An object must send light to our eyes before we can see it. You can understand, therefore, that objects which do not produce and send out light of their own must be lighted by some source of light. If we are to see an object, light from the luminous source must be *reflected* from the

object to our eyes. Light is reflected from objects in somewhat the same manner that a ball is bounced off a building. Light from the sun or from a lighted lamp travels to the object, "bounces" off the object, and some of it enters our eyes. When light does this, we say that the object reflects light.

In Problem 2 you will learn more about how light is reflected. All you need to know now is that you see an object either because the object itself is luminous or because it receives light from some object that is luminous. For example, you see an electric lamp because it sends light directly to your eyes. You see a book because it reflects the light from the sun or from an electric lamp to your eyes.

Self-Testing Exercises

1. Why can you see nothing in a totally dark room?
2. Is it correct to say that anything which can be seen is luminous? Explain your answer.
3. Explain why the book that you are now reading can be seen.

Problem to Solve

Is the moon luminous? Explain.

WHAT HAPPENS TO LIGHT WHEN IT STRIKES MATERIALS? You have already learned one thing that can happen to light when it strikes a material. It can be reflected. Whenever you look through a window-pane, you are making use of another way that light behaves when it strikes a material. It passes right through the glass to your eyes, and you can see things outdoors almost as well as if the glass were not there. We say that a material such as glass is *transparent.* Air and cellophane are two other transparent materials.

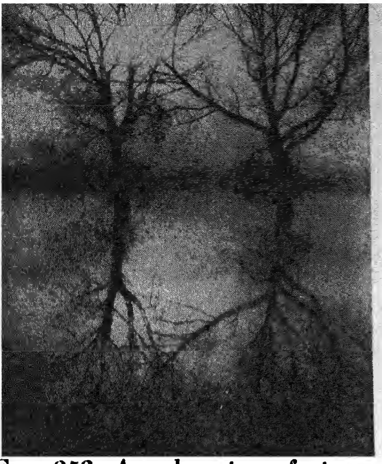


Fig. 353. An almost perfect reflection in the quiet water (©Fox Photos, Ltd.)

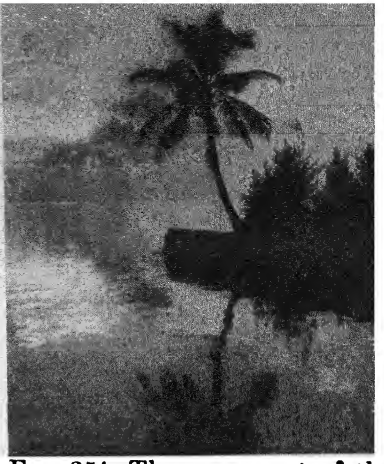


Fig. 354. The movement of the water changes the image of the trunk of the tree.

light, because it is not quite smooth. It may look smooth, but even the smoothest-looking paper has a surface of tiny hills and valleys. When light strikes such a surface, it is scattered in all directions (Figure 352).

You can see the difference between regularly reflected light and diffused reflected light by looking at the reflection of trees in a pool of water. Or you can pour some water into a dish and place one or two objects near it, so that you can see the reflection in the water. When the water surface is perfectly still, the picture in the water is a clear-cut reflection of the trees or objects. In fact, you can sometimes take pictures so that it is almost impossible to tell which is the object and which is the reflection (Figure 353). When the water is disturbed by waves, then the reflection is irregular, and the objects do not appear as a true picture. There is still reflection, but the irregular surface prevents regular reflection.

In using the reflection of light you must remember what you learned in Experiment 31. Materials differ a great deal in their reflecting power. Bright objects or light colors reflect a great deal of light. This is why they

FIG. 355. Notice how differently the light is reflected in different parts of this picture. The almost white concrete reflects much light. If the whole pavement were black, like the strip of tar in the center, automobile lights would show the driver almost nothing other than the pavement a few feet ahead of the car. (Ewing Galloway photo)

appear bright to you. Dark-colored objects or dull objects absorb light and reflect very little. Experiments have shown that white walls reflect about 80 per cent of the light that falls on them; medium gray reflects about 35 per cent; dark brown, 15 per cent; dark green, 5 per cent; and black, practically none. You will see later that the per cent of light reflected from different colors is of great importance in decorating a room.

Now that you know how light is reflected, you can explain many things. In a dark motion-picture theater you seem to see the beam of light from the motion-picture machine. What you really see is the light reflected from the countless dust particles in the air. You can test this for yourself. Let a beam of sunlight fall through a small opening under a curtain. Clap two erasers in the beam of light. What happens?

What you have just learned shows you why it does not get dark immediately after the sun goes down. The sun has gone behind the curve of the earth, but its rays are still shining through the air above your head. When the

light falls on the dust particles and other substances in the air, it is reflected or diffused. You can also understand why dark-colored roads are hard to see at night, and why white lines are often painted down the center. At dangerous turns in the road a white fence is often built. The white paint reflects the light from the headlights of cars so that drivers can see where the center of the road is and where the turns are. Now you know why it is lighter on a night when snow is on the ground. If you will look around you, you will find that the way light is reflected from different objects, surfaces, and colors explains many things about their appearance.

Self-Testing Exercises

1. Make a drawing of a mirror with a candle at one side of the mirror. Then draw an eye to show where you would have to be to see the candle in the mirror. Explain how you determine just where to place the "eye."
2. How do you account for the difference between light reflected from a mirror and light reflected from a piece of white paper? (Refer to Experiment 34.)
3. Why do some objects appear dark while others appear light or bright?

Problems to Solve

1. Why does a wet spot on pavement shine?
2. If the paper of a book is very glossy, it is hard on the eyes. Explain.

HOW DO WE USE MIRRORS? You have been looking at mirrors all your life. But have you ever studied a mirror? For example, when you look in a mirror, does the right side of your body appear on the right side of the image in the mirror or on the left side of the image? To answer this question you must remember that your image

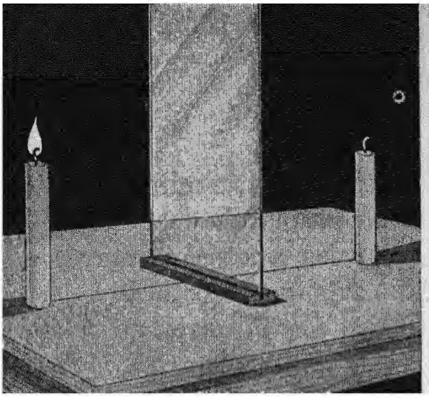
FIG. 356. Some of the people in this crowd are using periscopes to see over the heads of the other people. (Fox Photos, Ltd.)

is facing you. If you put your finger over your right eye, it will appear over the left eye in your image. We say, therefore, that images in a mirror are reversed. If this is true, how would a word written on a piece of paper appear if held up and read in the mirror? Try it and see. Were you right?

Another strange thing about a mirror is that you can see yourself walking toward or away from a mirror. Did you know this? Try it. When you stand in front of a mirror, you will see that your image appears as far back in the mirror as you are in front of it. You can easily prove that this is true.

EXPERIMENT 35. *How Can We Prove That the Image in a Mirror Appears as Far Back in the Mirror as the Object Is in Front of the Mirror?* Set up a sheet of glass in a room that is not too light and where there is no strong light behind the glass. Under this condition the glass will reflect light as a mirror does. Place a lighted candle in front of the glass and an unlighted candle behind the glass (Figure 357). If you look into the glass, you will see the reflection of the lighted candle in front of the glass, and you will also see the real candle through the glass.

Now move the lighted candle about so that its image fits on the image of the unlighted candle, no matter from what angle



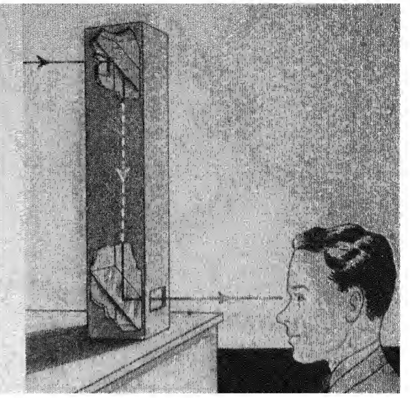
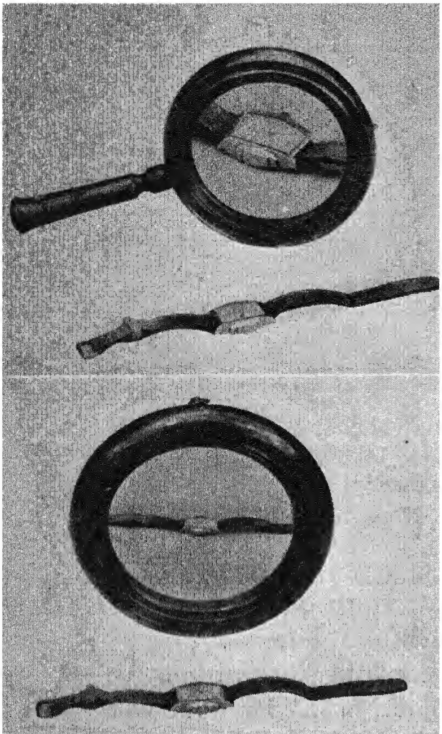


FIG. 357. Apparatus for Experiment 35 FIG. 358. A periscope

you look at it. Then measure the distance from the glass to the lighted candle and the distance from the glass to the unlighted candle. What do you find?

Watching a circus parade is fun if you can get in the front row where you can see it. Sometimes, however, you cannot see over the heads of the people in front of you. Figure 356 shows what many people did in looking at the coronation parade of King George VI of England. Do you see the queer-looking boxes? You can understand what the boxes were if you look at Figure 358. This picture shows a *periscope*. It has two mirrors in it, one at the top and one at the bottom. The lines show what happens to the rays of light. The periscope works on the principle that the angle of reflection equals the angle of incidence. Wooden periscopes like these were often used in the Great War by soldiers. Submarines, as you know, use periscopes to see what is going on around them when they are submerged.

So far, we have been talking about *plane mirrors*, that is, mirrors that are not curved. Your father may use a curved mirror when he shaves. If you will look into this mirror, you will see that it makes your face look much larger. This mirror is a *concave* mirror; that is, it is curved, or caved, inward like a shallow plate. You have surely



concave mirror. At the bottom is a convex mirror.

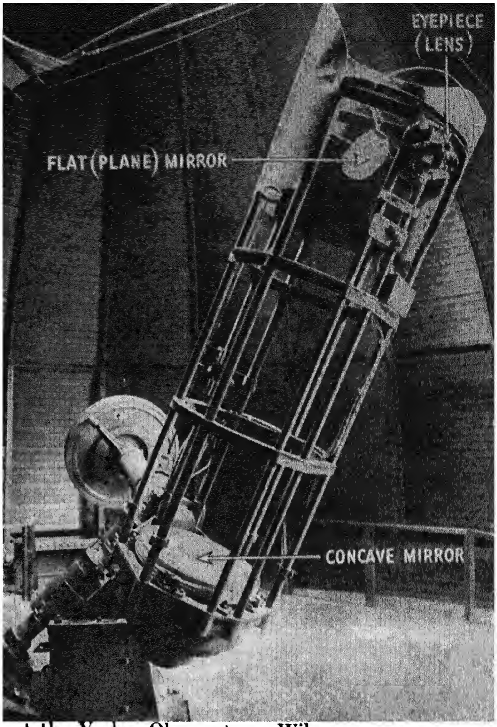
seen the little mirror on a long handle that the dentist uses. This is also a concave mirror and makes your tooth look larger. Just why this happens is too difficult to explain fully here. In general, it happens because a curved surface reflects light differently from a plane surface.

You can see another way in which curved surfaces affect the reflection of light if you will look at yourself in the polished back of a spoon. Turn the spoon in different ways and see how different you look. This, with the concave mirror, is the explanation for the mirrors that carnival companies have. The back of a spoon is a *convex mirror*. You note that you appear much smaller. An important use of the convex mirror is for rear-view mirrors on trucks and automobiles.

In *Book 2*, page 60, you had one example of how a concave mirror is used. Reflecting telescopes use mirrors of this type. Light falling from a distant star falls on this mirror. The mirror reflects this light in such a way that all the light collected is concentrated, or *focused*, on a certain point. Therefore it is more intense when it strikes that point. A plane mirror is placed at this point, and it reflects the light through the eyepiece of the telescope. A concave mirror of the correct shape concentrates at one point all the light received over the whole surface

of the mirror. This intense light makes it possible to see stars that are not visible in any other way.

Brightly polished metal mirrors are used in automobile headlights. The peculiar shape of the headlight makes it possible to send out rays that shine only on the road when the light bulb is in just the right place. This helps to prevent a glare in the eyes of the driver whom you are passing. Notice, however, that in the case of each ray, the angle of reflection is equal to the angle of incidence.



at the Yerkes Observatory, Williams Bay, Wisconsin

Self-Testing Exercises

1. What does Experiment 35 show you about the image that you see in a mirror?

2. Explain how a periscope is made so that you can see around corners with it.

3. If you stand in front of a plane mirror, do you look the size you really are or smaller or larger? In front of a concave mirror how would you look? In front of a convex mirror how would you look?

4. Why is a concave mirror used in a reflecting telescope?

Problems to Solve

1. Clothing stores have mirrors arranged so that the customer can see the back and sides of his body at the same time. Make a drawing that will show how these mirrors are arranged.

Check your drawing by comparing it with the mirrors in some store in your town.

2. Why can you usually see yourself in the plate-glass windows of stores?

3. Some signs along the highway seem to become luminous when they are lighted from an automobile headlight. Find out how the signs are constructed. There are a number of ways of making them.

4. Can one see through a brick? You can make it seem as if this is possible if you will arrange an apparatus like the one shown in Figure 361. You can make the tubes of cardboard, and you will have to bore holes in the board, as shown by the dotted lines. The only difficult part of the apparatus is to get the mirrors at the right angles.

5. In some stores "invisible" show windows are used. Find out how they work.

6. Hold a brightly lighted pin close to a mirror in such a way that you see the image of the pin at a more oblique angle than is shown in Figure 350. Do you see one or two faint images of the pin in addition to the clear image? Explain why you see what you see.

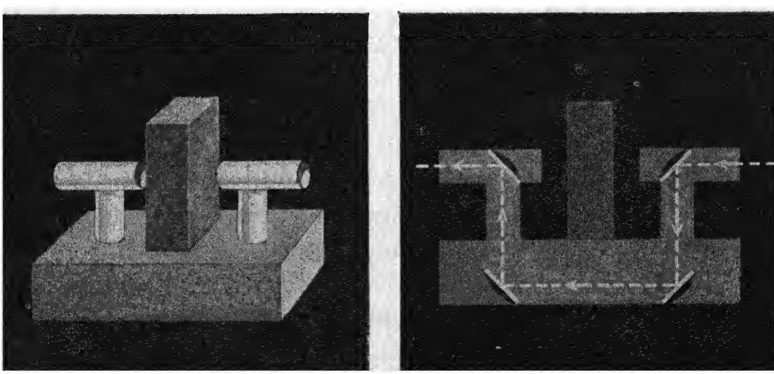


FIG. 361. These two pictures show you how to set up an apparatus that enables you to see through a brick.

FIG. 362. The eyes suffer little strain in surroundings like this. (Ewing Galloway photo)

FIG. 363. This is the kind of use that puts a strain on the eyes. (Ewing Galloway photo)

Problem 3:

HOW DO WE USE LIGHT IN OUR HOMES?

HOW MUCH LIGHT DO WE NEED IN OUR BUILDINGS? So far as we know, the eyes of man today are no different from the eyes of primitive man, who lived perhaps a hundred thousand years ago. Eyes, like other parts of living things, are adapted to the kind of environment in which a living thing spends its life. The human eye developed in such a way as to adapt it to the conditions in which man lived. Let us look at these conditions. Primitive man worked or hunted in the daytime. For light he used the direct light from the sun or the diffused light reflected from particles in the air, the trees, the soil, and other surfaces.

To see how much light this is, we need a unit to measure how strong or how intense a light is. The unit used is called a *foot-candle.* A foot-candle is the brightness of the illumination provided by a candle at a distance of one foot. The candle must be just a certain size and burn oil at just a certain rate. You can get a better idea of how much light this is if you will hold a printed page at a distance of one foot from a lighted candle in a dark room.

As you can see, a foot-candle is very little light. On a bright sunny day the sun furnishes us with an *illumination* of about 10,000 foot-candles. On a cloudy day, of course, the illumination is much less, but it rarely falls below several hundred foot-candles. On a shady porch on a sunny day the illumination is about 500 foot-candles. Do you see that our eyes are adapted to outdoor conditions in which hundreds or thousands of foot-candles of illumination are available?

Primitive man did little work of a close nature, that is, work that had to be held at a distance of one or two feet from the eyes. He did not sew with fine thread; he could not read; his art was very crude, and so were the tools he fashioned. He did not spend long hours each day using his eyes constantly for close vision. He used his eyes mostly in hunting and in other long-distance seeing. As a result, the eyes of human beings are best adapted for seeing at distances of twenty feet or more.

Modern conditions have brought about great changes in the way we use our eyes. Our eyes have not changed; they are still best adapted to the kinds of surroundings that primitive man had. Today, however, we do much of our work indoors, where the light is far different from the light out-of-doors. Tests of lighting conditions in factories have shown surprising results. Even at a distance of a few feet from a window on a sunny day, the illumination may fall to as low as 20 foot-candles. Near the wall, on the other side of the room, only one or two foot-candles of illumination may be present. The kind of work done has also changed. Now most of our work is done at a distance of from one to two and a half feet from the eyes. Furthermore, our eyes are in almost constant use.

It is no wonder, then, that so many people have trouble

with their eyes. Their eyes are not adapted to the kinds of uses to which they put them. In the United States one out of every five children in elementary schools, two out of every five students in college, and three out of every five old people have defective eyes. Figure 364 shows the per cent of people in different occupations who have eye diseases or whose eyes show eyestrain. The farmer and laborer work under conditions most like those of primitive man. Men in these occupations have the least trouble with their eyes. As you look at Figure 364, you can see that eyestrain and diseases of the eye are most frequent in people who use their eyes for close work.

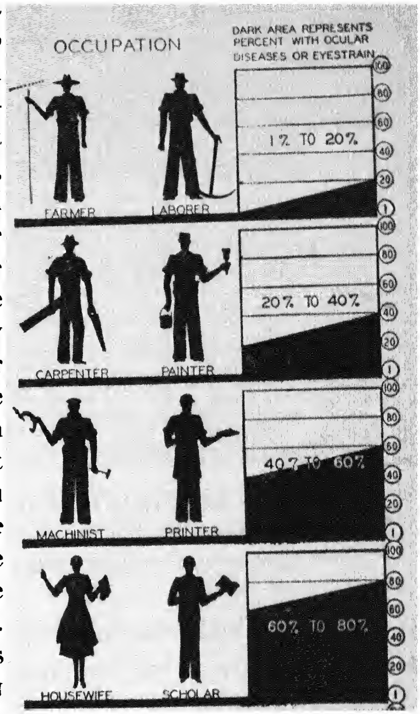


Fig. 364

How do we get the right kinds and amounts of light in our buildings? What are we going to do about this constant strain on our eyes? We cannot go back to living in the manner that primitive people lived. Even if our eyes are not adapted to present conditions, we have to use them. There are two things we can do to help our eyes: First, we can learn how to take care of our eyes to avoid eyestrain. This you will learn about in a later problem. Second, we can provide for the proper lighting of our homes. We can see to it that we get enough light to do what we have to do.

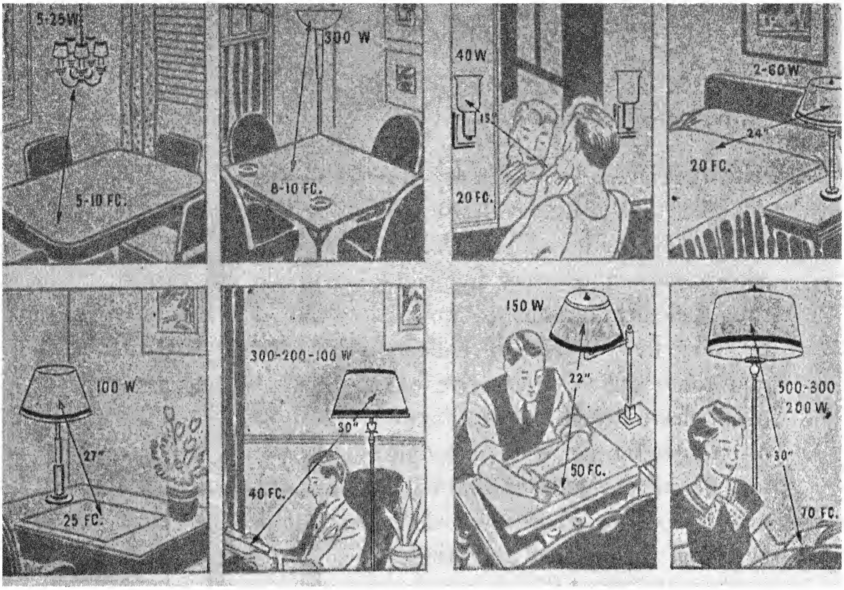


FIG. 365. Study these pictures carefully. They show you how many foot-candles of light are needed for various uses of the eyes and how many watts of electricity are needed.

With the invention of the *light meter* (Figure 367), lighting has become a science. By this instrument it is possible to tell how much light is needed for different purposes and the kind and number of lamps needed to supply this light. The results of experiments show the following light needs: (1) For use in the dining-room, at a card table, and other eye work not requiring close sight—10 foot-candles or less. (2) For reading good print on white paper, coarse knitting, ironing, cleaning vegetables, etc.,—10 to 20 foot-candles. (3) For intensive use of eyes, such as sewing at machines, studying, and drawing—20 to 50 foot-candles. (4) For reading fine print, sewing with dark thread on dark goods, etc.—50 to 100 foot-candles.

Figure 365 shows examples of the sizes of electric lamps needed to supply the correct amount of illumination. You will notice in these figures that the distance from the lamp to the work is given. In placing lamps it is always

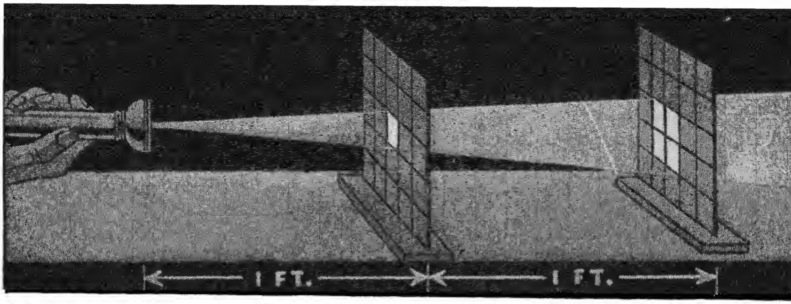


FIG. 366. Apparatus for Experiment 36

necessary to consider this distance, as you will see from the following experiment.

EXPERIMENT 36. *What Effect Does the Distance from a Source of Light Have upon Its Intensity?* In a dark room place a candle or electric flashlight one foot from a cardboard that has a hole one inch square at the center (Figure 366). Allow the light to pass through the hole in the first cardboard and strike a second cardboard, which is marked off in square inches and which is held two feet from the candle. How many square inches does the beam of light cover on the second cardboard? Move the second cardboard three feet from the candle. How many square inches of space are covered by the beam of light?

From this experiment you see that the intensity of light becomes less as you go away from the source of light. You see that the light is only one-fourth as intense at a distance of two feet as it is at a distance of one foot. This is true, as the experiment showed you, because the light is scattered over four times as much space if the distance is doubled. In other words, at 15 inches a lamp may

FIG. 367. A light meter (General Electric photo)

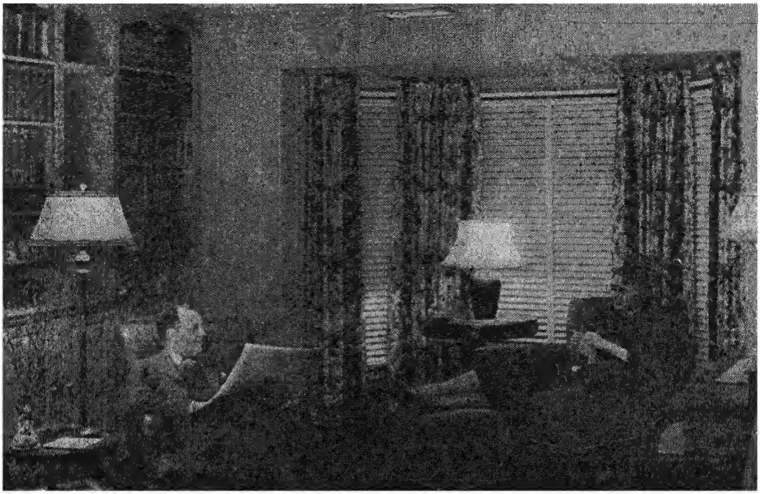


Fig. 368. Notice how well lighted all parts of this room are. Floor and table lamps provide light for close work and are shaded to keep direct light from the eyes. Overhead is a ceiling light covered with frosted glass to give a soft, diffused light to all parts of the room. (General Electric photo)

supply 20 foot-candles of illumination. At 30 inches the same lamp would provide only five foot-candles.

If you examine each lamp at home to see the size of lamp bulb and the distance the lamp is from your work, you can, by comparing it with the examples in Figure 365, tell whether you are getting enough light. If you are not getting enough light, either use a larger electric lamp or move closer to the lamp. The lamp should be far enough away from you to light your entire work. In most cases it is better to increase the size of the light bulb.

So far you have been learning about the amount of light needed for work that you are doing. This is called *local lighting*. In addition, there should be *general lighting* for the room. This is usually provided by a central lamp in the ceiling. Lamps in the ceiling are generally of three types. In *direct* lighting the light comes directly from the lamp. Frosted glass bulbs that diffuse the light are much better than plain glass bulbs. In the *semi-direct*

method a translucent frosted bowl is placed under the lamp. Some of the light passes through the bowl and is diffused; some is reflected by the bowl to the ceiling and then comes back to the room. This combination of diffused light and diffused reflected light is most pleasing to the eye.

In the *indirect* method the bowl under the light is opaque, so that no light can come directly to the room. It is all reflected to the ceiling and then comes back to the room. Floor lamps are also made to light a room by this method. This is an excellent method for general lighting, because the diffused light is very soft and pleasing to the eye.

Self-Testing Exercises

1. To what kinds of conditions are the eyes of man adapted?
2. Make a list of the ways in which you use your eyes. Place an "A" before the ways to which our eyes are naturally adapted and an "N" before the ways to which our eyes are not adapted.
3. Make a drawing that will show why the light is only one-fourth as intense if the distance from the source is doubled.
4. What is the difference between general lighting and local lighting?
5. What is the difference between direct lighting, semi-direct lighting, and indirect lighting?
6. What are the advantages and disadvantages of each method of lighting?

Problems to Solve

1. Make a drawing showing the location and candle-power of the lamps and the location of the furniture in your living-room at home. Compare with Figure 365. Do you think that the room is lighted adequately?
2. Make a drawing that will show why frosted electric lamps give a softer light than bulbs made of plain glass. Explain.

Problem 4:

HOW DO WE USE LENSES?

WHAT HAPPENS TO LIGHT WHEN IT PASSES THROUGH A LENS? Do you know that you are using lenses right now? You need not look for them, because you cannot see them. They are in your eyes. Without them you could not read this book. If the lenses in your eyes are not working right, you probably have a pair of lenses balanced on your nose. You have seen lenses used for other purposes. The simple microscope, or magnifying-glass, that makes small objects look larger than they really are is a lens. The compound microscope that makes it possible to see objects too small to see with the naked eye contains lenses. So do telescopes and field-glasses. Movie projectors use them. The pictures on the motion-picture film are only about the size of a postage stamp, but lenses make them cover a large screen many feet away.

If you examine the lenses in these different instruments, you will find that they are all alike in one way: they are merely pieces of curved glass. They differ only in the way the glass is curved. Different effects are obtained by varying the shapes of the lenses and by grouping them in certain ways. If you will try the following experiment, you will find out something about lenses that you probably do not know.

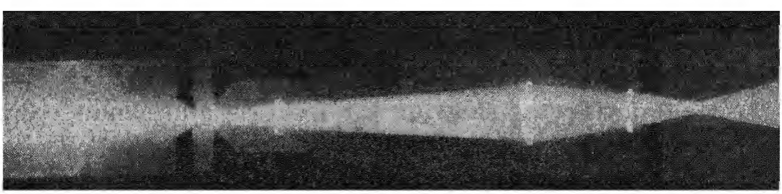


FIG. 369. An X-ray photograph of the path of the light through the lenses of a telescope (Bausch and Lomb photo)

Experiment 37. *How Can a Lens Be Used to Project a Picture of the Out-of-Doors?* Choose a bright sunny day. Get a convex lens; that is, a lens that is thicker in the middle than it is at the edges. Hold the lens in front of a window. Then hold a piece of white cardboard behind the lens at a distance of two or three feet. Bring the cardboard closer and closer to the lens. Watch what happens. Do you see the window and the scene out-of-doors? Is the *image* (picture) you see right side up or upside down? When the image can be seen most distinctly, we say that the lens is *focused.*

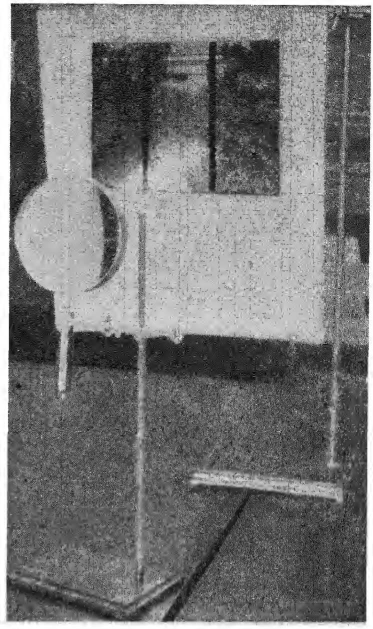


Fig. 370. Apparatus for Exper. 37

This simple experiment shows you what a lens can do to light. You have a lens in your eye. It forms pictures on the back of your eye. There is also a lens in a camera. It forms a picture on a sensitive plate or film in the camera. You will learn more about how the eye and the camera work later in this unit. Before you can understand what happens to light as it passes through a lens, you will need to do another experiment to get some more facts about lenses and light.

Experiment 38. *How Do Lenses Affect Rays of Light?* (*a*) Obtain a reading glass (a double convex lens). Darken the room and light a candle. Hold the lens a foot in front of the candle (Figure 371) and then hold a piece of paper back of the lens where a distinct image of the candle appears on the paper. The candle is then said to be in *focus.* In what way is the image

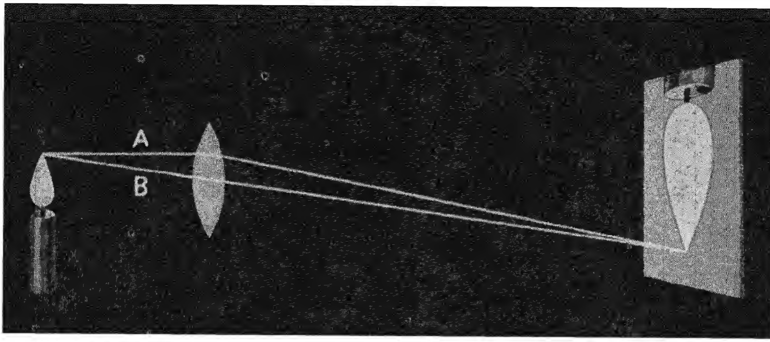


FIG. 371. Apparatus for Experiment 38

of the candle different from the candle? Measure the distance from the lens to the paper.

b) Now repeat part *a*, moving the candle two feet from the lens. Move the paper so that the candle will be in focus. Did you move the paper nearer to or farther away from the lens?

c) Repeat part *a* of the experiment, using a lens that is either more convex or less convex than the first lens. Which lens brings rays to a focus in the shorter distance?

First of all, we must explain why the lens forms an image of the candle on the screen. A diagram will make this clear (Figure 371). We will let lines represent rays of light from the candle. First we will draw line A from the top of the candle flame to the lens. We see by our drawing that the top of the candle comes to a focus on the bottom of the image. Therefore we must draw line A so that it will come to a focus at this point. The continuation of line A will therefore be bent downward. This bending of the light is called *refraction*. We say that the ray is *refracted*.

The ray of light, B, that passes through the center of the lens goes through without bending and intersects line A on the screen. The point at which these two lines intersect is the focus. All other rays of light that strike the lens from the tip of the candle are bent to come to a focus at the same place. Therefore a bright spot appears on the screen at that point. Light from each other part

of the candle acts the same way and is focused at the right point on the screen. All this light forms the image on the screen.

Our drawing shows us that rays of light are refracted, or bent, by a convex lens. That is the reason why the lens can form an image. You have seen that rays of light can be refracted when you used a burning glass. In this case the rays of sun that strike the glass are bent so that they come to a focus at a certain point (Figure 372). The rays are bent as they pass from the air through the lens because light travels more slowly in glass than in air. Just how this bends the rays, you will find out later if you study about the theories of light in physics. You also found in the experiment that the farther away the candle was from the lens, the closer the focus was to the lens. Of course the reverse is true also.

You can see now why you must focus your camera to get a good picture. The camera has a lens, and the rays of light are brought to a focus on the plate or film (Figure 374). To take a picture of someone, you stand far enough away so that you can see the person in the view-finder. The view-finder shows you just what will be visible in

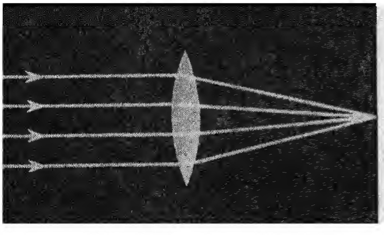


FIG. 372. This drawing shows the focusing of light rays that pass through a convex lens.

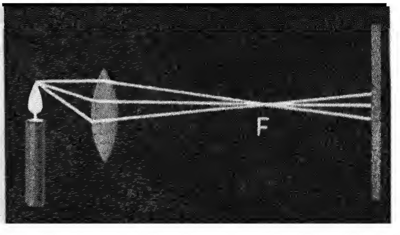


FIG. 373. Which way would you move the lens to make the light rays focus on the screen?

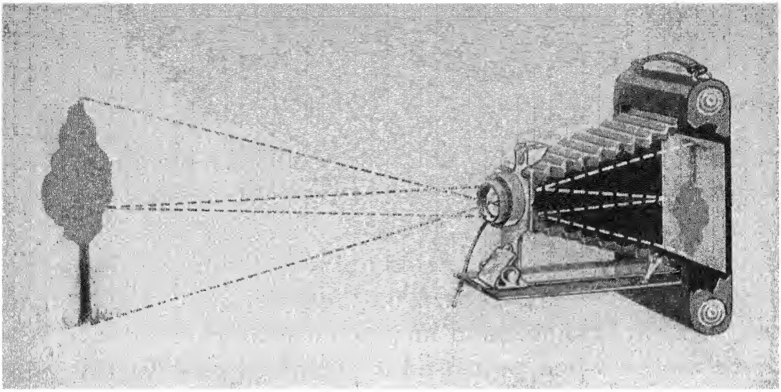


FIG. 374. How the lens of a camera makes an image on the film

your picture. Before you take the picture, however, you must be certain that the rays will come to a focus on the film. You first estimate the distance; then you set your lens for this distance by moving it in or out. A scale on the camera shows you the correct place to set it. Many people think that they have the camera in focus if they see a person in the view-finder. The view-finder, however, has nothing to do with the focus. It merely shows you what you will see in your finished picture. The correct focus is obtained by moving the lens in or out.

You also found in our experiment that the thicker the center of the lens, the more it bent the light rays. In other words, the more convex the lens, the closer the focus will be. You will see later how this idea helps you understand how the lenses in your eyes work (Figure 376).

So far we have been discussing what happens to light as it passes through a convex lens. You have seen that the rays from any point are bent so that they come together at a point (focus) behind the lens. If you use a concave lens, the effect is just the opposite (Figure 375). The rays are bent out rather than bent in. As you can see, such rays cannot come to a focus; therefore a concave lens cannot be used to throw an image on a screen. You will see later how some concave lenses are used.

Self-Testing Exercises

1. What is meant by the term "focus?"
2. In what ways does the image projected on a screen by a convex lens differ from the object itself?
3. When an object is moved closer to a lens, how must the screen be moved to put it at the new focus?
4. When an object is moved farther away from a lens, what must be done to the screen to have it at the new focus?
5. How is a camera focused correctly?
6. Suppose that you have two convex lenses, one of which is more convex than the other. Which one would you use to bring the rays to a focus at the shortest distance from the lens?
7. Why is it impossible for you to bring the light rays to a focus with the use of a concave lens?

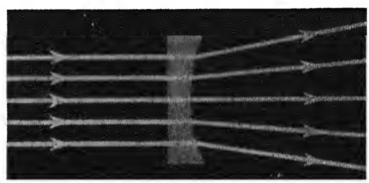


FIG. 375. How light rays are affected by a concave lens

Problems to Solve

1. How would you perform an experiment to discover which of two convex lenses is the more convex?
2. Remove the back of a camera. Place a piece of glazed paper over the back. Point the camera at some object and then move the lens back and forth until the image is focused on the paper. This will show you why the correct focus must be made in a camera to get a good picture.
3. Why can a convex lens be used as a burning glass, while a concave lens cannot be so used?
4. Examine a view-finder on a camera. Find out how it works.
5. Fill a small, flat bottle with water. See if you can make it act like a lens. Do the same with a spherical glass flask, or use two watch crystals fastened together with adhesive tape and filled with water.

How do we see? You already know that the eye has a lens. It works just like any other double-convex lens. Rays of light are bent and brought to a focus on a thin coat, called the *retina* (Figure 376), which lines the inside of the eyeball. Perhaps you wonder if the images formed on the retina are upside down. Yes, they are. Our brain, however, interprets these images to be what they really are. So we actually see things as they should be.

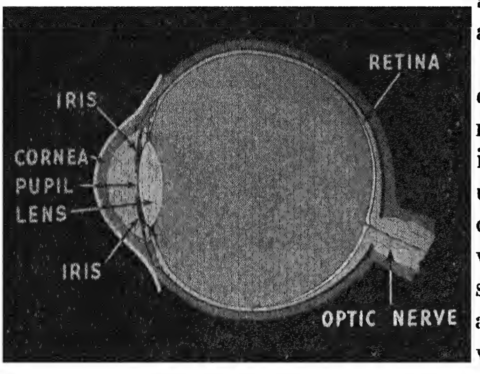


Fig. 376. Diagram of the eye

An American psychologist once had a pair of glasses made that would turn the images in his eyes right-side-up. When he put them on, a ceiling light looked as if it were on the floor. A flight of stairs leading upward looked as if they were leading downward. For a few days he had a terrible time bumping into things and adjusting his habits to this change. Soon, however, he became adjusted. Things seemed to be where they should be. What do you suppose happened when he took off the glasses? The world was topsy-turvy again. So he had to learn all over. We do not know how the brain interprets things, but this experiment shows that it does. We see things right side up, even if their images are upside down in our eyes.

If you will hold a pencil in front of your eyes and focus your eyes upon it, you will get a clear picture of the pencil; but you will notice that objects in the background are not clearly defined. Now if you will look beyond the pencil to something in the background, you will see that these

objects are quite clear, but that your pencil is not. Your eyes cannot bring two objects at different distances from your eyes in focus at the same time. This you would expect, because Experiment 38 showed you that objects which are at different distances from a lens are brought to a focus at different distances behind the lens.

This brings us to the question, How can the lens in the eye bring objects at different distances into focus? If you will look at Figure 376, you will see that the lens in the eye is attached at the edge with fibers. At the outer ends of the fibers is a muscle in the form of a circle all the way around the inside of the eyeball. The lens itself is made of a somewhat flexible material that can change its shape. The muscle is attached in such a way that the pull on the fibers to the lens can be changed. When the muscle is relaxed, or loose, the eyeball tends to pull out on the fibers and make the lens flatter and less convex. When the muscle contracts, the fibers are loosened and the lens becomes thicker in the center, or more convex.

Experiment 38 showed you what happens when lenses of different curvatures are used. The more convex a lens is, the shorter the focus. The less convex the lens, the longer the focus. Now let us see what happens to the lens when you look at an object close to your eyes. The closer the object is, the farther back the light will be focused. This may be so far back that the eyeball will not be long enough. How can the image be brought to a focus on the retina? To bring it to a focus on the retina, the circular muscle contracts and loosens the fibers that hold the lens. Then the lens becomes more convex. This bends the rays more, so that they focus on the retina. If the object is farther away, the muscle relaxes and allows the fibers to pull on the lens, which makes it become less convex.

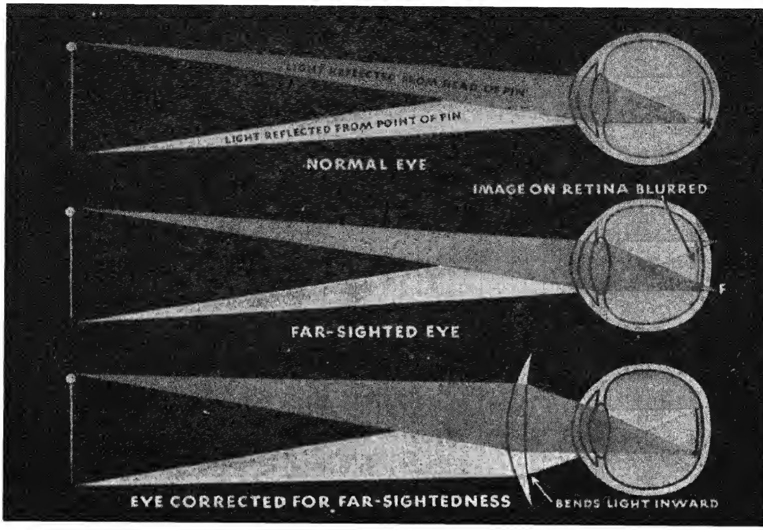


FIG. 377. How the light rays focus in a far-sighted eye. The letter "F" is at the point where the images are brought to a focus.

Our eyes thus bring images to a focus on the retina by changing the convexity of the lens.

Unfortunately, our eyes are not always constructed so that a correct focus can be obtained. Some people are far-sighted; that is, they can see distant objects clearly, but not objects that are close at hand. This means that the lens does not focus the light properly. It tends to focus too far from the lens (at F in the far-sighted eye, Figure 377). Sometimes this is caused by the shortness of the eyeball. At other times it is caused by the inability of the lens to adjust itself to near objects.

When one gets older, the lens often loses some of its elasticity, so that it cannot become as convex as it once did. To correct far-sightedness, we wear slightly convex glasses. These convex glasses help to bend the light rays in, so that they will come to a correct focus closer to the lens. Thus the image of near objects on the retina is distinct. Since people's eyes differ greatly, glasses should be fitted only by experts.

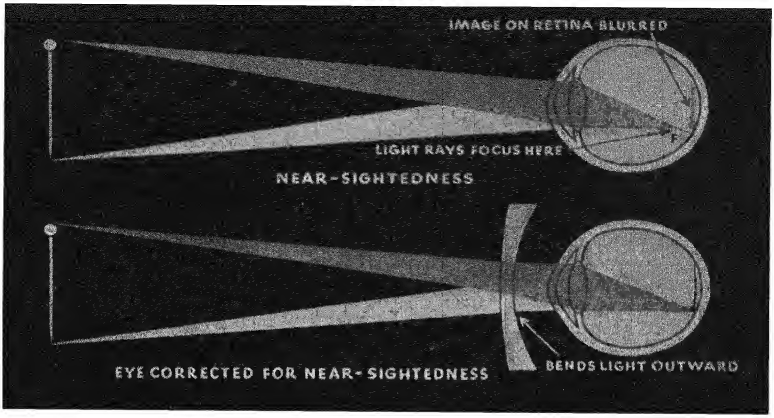


Fig. 378. How the light rays act in a near-sighted eye

The opposite of far-sightedness is near-sightedness (Figure 378). This is caused by conditions that are just opposite to those we have named for far-sightedness. The eye bends the light rays too much, or the eyeball is too long. The light rays tend to focus in front of the retina, and the image of a distant object is blurred on the retina. To correct near-sightedness, slightly concave glasses are used.

Some people have what is called *astigmatism*. This may happen when the eyeball is curved somewhat like an egg instead of being spherical. In such eyes lines that run in one direction are seen quite distinctly, while those that run in the other direction are blurred. Eye-glasses with lenses that are specially ground can be made to correct this defect.

Since your eyes are so important to you, you must take good care of them. First, you should be sure that you do not need glasses. If you find it difficult to read what your teacher puts on the board, or if the writing appears blurred, you may need glasses. For most people a distance of about twenty inches from the eyes is best to get a clear vision of the printed page. If you have to hold your book much farther away or much closer to your eyes, you may be far-sighted or near-sighted. Headaches are often

FIG. 379. With diffused light coming from the tall, well-shaded lamp, the boy can see easily and study his lessons without eyestrain.

FIG. 380. Here there is a glare of light on the book, and some light shines directly into the boy's eyes.

caused by defective eyes, too. If your school does not have an instrument for testing your eyes, you should go to an expert in this kind of work.

Perhaps you have noticed that your eyes get tired when you read for a long time or do other kinds of close work. When you are reading, the circular muscles around the lenses of your eyes are contracted. After a long time they become fatigued. To avoid this, it is a good practice to look away occasionally and focus your eyes upon some distant object. Too much light or too little light will also cause eyestrain. Figure 379 shows a good way to light a desk. Notice that light does not shine directly from the lamp into the eyes of the boy. Direct sunlight on a paper or a book is especially hard on the eyes of most people.

Self-Testing Exercises

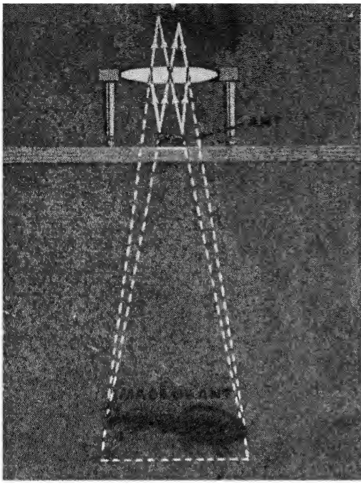
1. What method of focusing is used by the eye?

2. What conditions bring about near-sightedness? How is near-sightedness corrected?

3. What conditions bring about far-sightedness? How is far-sightedness corrected?

4. Why is it often impossible for older people to see near objects clearly?

5. State three things you can do to avoid eyestrain.



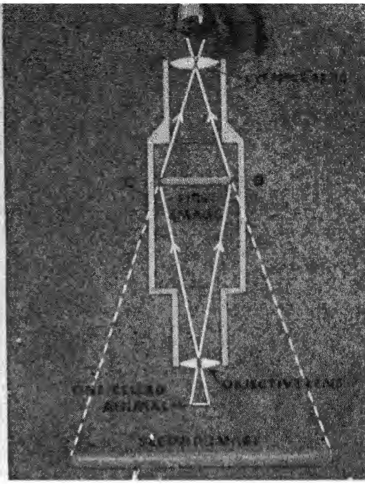


FIG. 381. How light rays travel through a simple magnifier

FIG. 382. How light rays travel through a compound microscope

Problems to Solve

1. Devise an experiment to find out if the glasses that you or some friend wears are convex or concave. What does this show about the kind of defect of the eye? Find out if both eyes are defective, or only one eye.

2. Find out what *bifocal* lenses in glasses are and why they are used.

3. When you change from looking at the blackboard to looking at a book, what change takes place in the lenses of your eyes?

HOW ARE LENSES USED IN OPTICAL INSTRUMENTS? To explain why microscopes magnify and telescopes and field-glasses make objects look nearer is too difficult to explain here. We can, however, explain how they are constructed and tell a little about how they operate.

First, let us examine a hand magnifier. It has a double-convex lens. If it is held close to an object, the object appears larger. If you study Figure 381, you can see how the light rays are bent. The rays are bent in when they pass through the lens. But our eyes see the rays as straight lines; therefore what we see is shown by the broken lines.

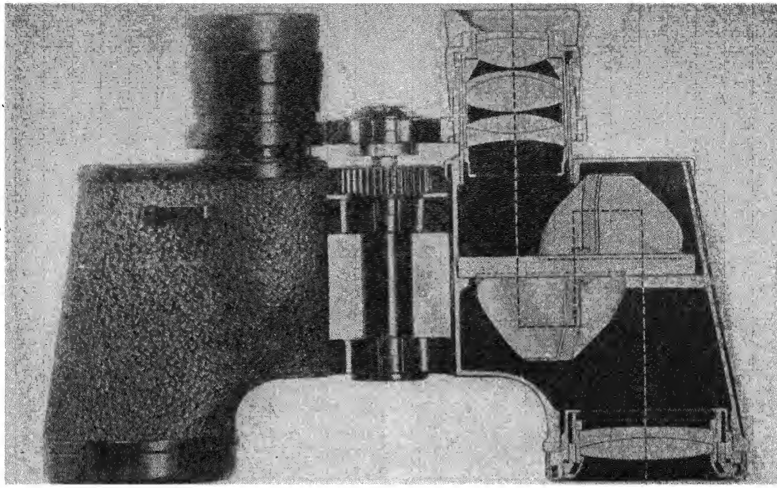


FIG. 383. Try to explain how the light travels through the binoculars. Where are the lenses in these binoculars? Where do you think the prisms are? (Bausch and Lomb photo)

In compound microscopes there are two lenses. Light from the object passes through the *objective lens* and comes to a focus at CD (Figure 382). There is no screen there, but if one were put in, you could see the image just as you did in Experiment 38. The eyepiece then magnifies this image just as it does in the simple microscope.

Telescopes also use two lenses. Light passes through the objective and comes to a focus at CD (Figure 384). This image is then magnified by the eyepiece, as in the simple microscope. The lenses are mounted in a sliding, or telescoping, tube so that the image can be brought into correct focus for objects at different distances. The image is inverted, and for this reason you see the object

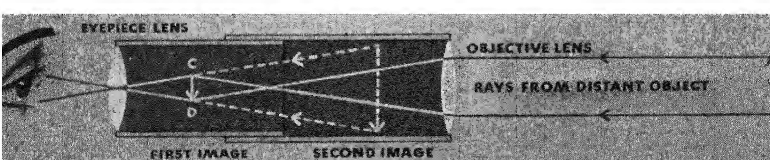


FIG. 384. How the lenses are arranged in a telescope

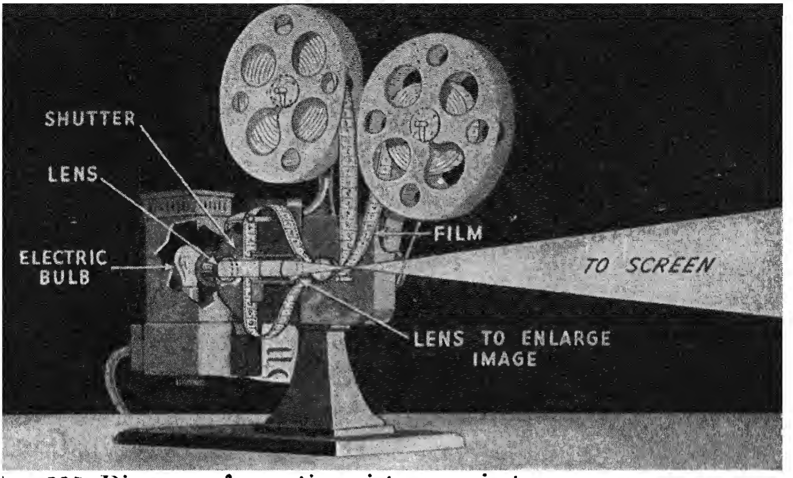


FIG. 385. Diagram of a motion-picture projector

upside down. Some telescopes have another lens that makes the image right-side-up.

Some field-glasses and opera-glasses use a combination of lenses and *prisms*. A prism is a triangular-shaped piece of glass. The combination of prisms used is known as a *reversing prism*. In such a prism the light is reflected four times. These reflections turn the image right-side-up (Figure 383). This kind of field-glass is very compact. By the use of prisms field-glasses have a magnification equal to a telescope that is three times as long.

Motion-picture machines also have a combination of lenses to project a picture on a screen. First of all, a powerful *arc light* or an electric bulb is used to supply the light. This light is concentrated on the film by a convex lens. On the film are countless separate pictures, each of which is about one inch long and about three-fourths of an inch high. In front of the film is a lens that forms an enlarged image on the screen. An electric motor is used to draw the film along at the rate of about sixteen pictures per second.

As each picture appears in front of the light, it stops for about one thirty-second of a second. While the picture

is still in front of the light, a shutter opens and allows light to pass through the picture. When the film starts to move again, the shutter is closed so that no light can pass through the picture. Then the shutter opens, another picture is seen, and so on.

What you really see, therefore, is sixteen still pictures per second. The pictures are shown so quickly that it appears as if the figures were moving. Actually, of course, the figures are not moving. Our eyes cannot instantly "forget" what they see. Each image leaves a picture on the retina for a fraction of a second. Before one image has faded from the retina, another is formed. As a result, each picture blends with the next, and you get the effect of continuous movement.

Self-Testing Exercises

1. Make a drawing showing how a simple microscope makes a pin look larger. Use Figure 381 as a guide to follow.
2. Make a drawing showing how a compound microscope makes a pin look larger. Use Figure 382 as a guide to follow.
3. Explain how a motion-picture projector works.

Problems to Solve

1. Explain why motion pictures flicker if the film is run too slowly.
2. If a motion-picture projector produces a picture that is too large for the screen, should the projector be moved nearer to or farther from the screen?
3. Olives look much larger in the bottle than they do when out of the bottle. Explain.
4. Prove that a motion-picture screen is not lighted all the time. To do this, move your hand back and forth rapidly before your eyes while you are watching a movie. What do you notice? Explain.
5. Learn how slow-motion moving pictures are made.

Problem 5:

WHY ARE OBJECTS OF DIFFERENT COLORS?

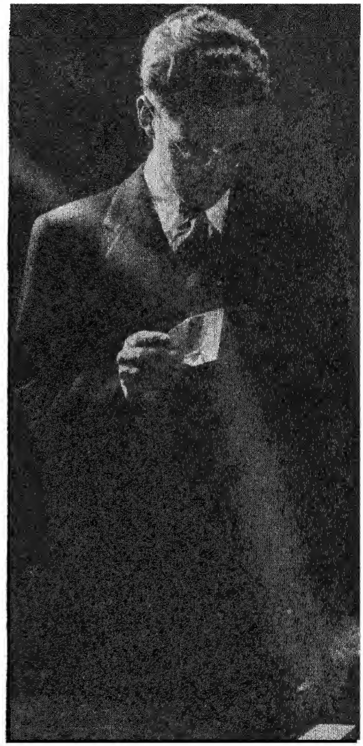
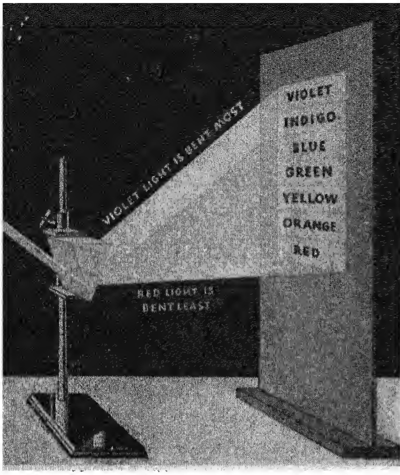


FIG. 386. How a prism bends light rays (Photo from *Nature Magazine*)

BEFORE YOU try to answer this problem, recall some of the experiences you have had in order to find some facts about color. Did you ever notice that a soap bubble has many different colors? You have probably seen these same colors reflected from oil on the pavement, or you may have seen them in a flaw in window glass. Can you explain how these colors are produced?

Perhaps you have noticed that things appear to be different in color under artificial light and in sunlight. If you choose a tie or dress under artificial light, you may be surprised to find that it looks quite different in the daylight. Curious things happen when you look at different colors under different colored lights. White paper looks white in the sunlight. If you throw a red light on it, it appears red; in a green light it looks green. A red dress in a blue light appears black. A blue dress appears black under a red light. These facts raise an interesting question: "Why do objects not always have the same color?" To answer the question, you will need to find out more about light.



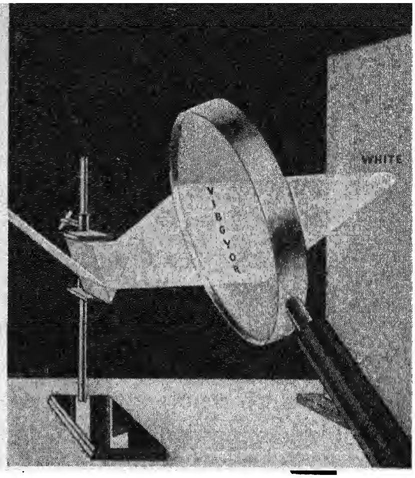


FIG. 387. How a prism separates the rays of light

FIG. 388. How a reading glass mixes the colored rays to make white again

EXPERIMENT 39. *What Colors Does Sunlight Contain?* Pull down the shade of a window so that only a narrow beam of sunlight can enter the room. Darken the rest of the room. Hold a glass prism in this beam of sunlight and put a white cardboard behind it (Figure 387). What do you see?

The band of colors that you see is called the *spectrum*. A spectrum consists of seven colors, red, orange, yellow, green, blue, indigo, and violet, that blend gradually into each other. These are the same colors that you see in the rainbow. If a reading glass is held in just the right place in the path of the rays that pass from the prism, the colors will disappear, and only a white spot will be seen on the screen (Figure 388). By now you are probably curious as to where these colors come from. They come from the white light of the sun. White light is really a mixture of these seven colors. The prism separates the complex white light into the different colors of which it is made.

Light is believed to travel in waves. These waves are somewhat like the waves of the ocean that you may have seen rolling into shore. Some of the waves are long; that

is, the distance between the crests of two waves is long. Other waves are short. In a like manner, each kind of color light has its own wave length. The wave length of red is .000028 inches. The wave length of violet is .000016 inches. If you will look at the colors made by the prism again, you will see that red is at one end of the spectrum, and violet is at the other end. The wave lengths of the other colors are in between the wave lengths of the red and the violet.

You know already that light waves are bent where they pass into glass. Different kinds of light waves (colors) are bent differently. The shortest light waves are bent more than the longer light waves. You can see, therefore, that violet light will be bent more than the red light. Since each kind of light wave is bent differently, the result will be bands of the different colors on the screen (Figure 387). Did it surprise you to learn that white sunlight is really a mixture of all the colors of the rainbow? You saw, however, that the colors could be mixed again to produce white light when a reading glass was held behind the prism.

As yet, we have not explained why objects differ in color. A white paper is white because it reflects all of the colors in sunlight equally. None of the colors is removed from the light; so the light that is reflected to our eyes is white light. A dress appears green because the dye in the dress absorbs all of the colors in the sunlight excepting green. The green is reflected to your eye; thus you see the dress as green. If a green dress is held in red light, it looks black. The green dye can reflect only green, and unless the dress is held in some light that has green in it, the dress cannot appear green.

You can see, therefore, why objects are colored. They have a certain color because they take out or absorb all

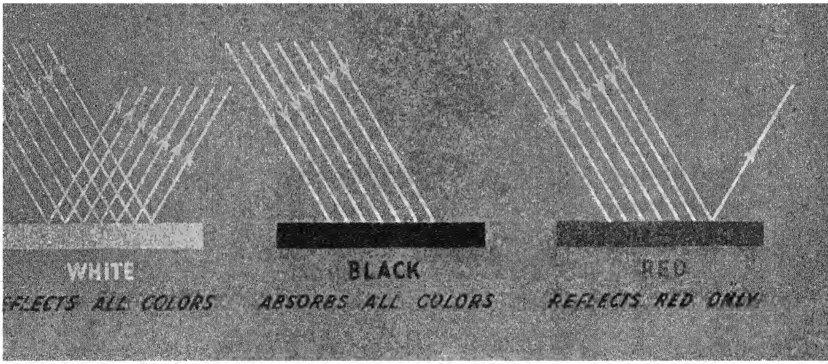


Fig. 389. How rays of light are reflected from different kinds of materials to show color

the other colors in white light. If they absorb all colors, then they are black (Figure 389). If they reflect all colors, they are white.

It is not quite correct to say that a green paint will absorb violet, indigo, yellow, orange, and red, and reflect only green. Most of the dyes and pigments that we use in paint are not true *spectral* colors; that is, they are impure colors. For example, a yellow paint usually reflects some green as well as yellow. More yellow than green is reflected; so it appears to be all yellow. A blue paint will also reflect some green. When yellow paint and blue paint are mixed, the resulting color is green. Let us see why. The yellow paint will absorb blue light, and the blue paint will absorb yellow light. Since the green light is not absorbed by either paint, it is reflected, and we see the paint as green.

Colors usually appear different under artificial lights from what they do in sunlight because artificial lights have less blue in them. As a result, blue looks very dark under artificial light. This is true because there is less blue to be reflected. Artificial lights have more red in them than sunlight. Red, therefore, looks much brighter because there is much red to be reflected. Many clothing stores have what they call daylight lamps to help their

customers in selecting colors. These lamps supply an artificial light that is much the same as sunlight.

Perhaps our most gorgeous display of color is provided by the rainbow. You can make an artificial rainbow if you will adjust the hose to make a fine spray of water. Spray the water away from the sun and stand with your back to the sun. Early morning or late in the afternoon is the best time. The colors are produced by the tiny drops of water in the same way that the colors are produced by the prism. The colors of the sunset are produced because particles in the air absorb most of the blue light rays, leaving the red and yellow to be reflected from the clouds.

Self-Testing Exercises

1. Describe an experiment to prove that white light is really a mixture of many colors.
2. Why does a prism separate white light into the different colors?
3. What determines what color an object will be?
4. A white dress will appear red in a red light and blue in a blue light. Explain.
5. Why do objects appear a different color under artificial light than they do in daylight?

Problems to Solve

1. If a black object absorbs all of the rays of light that it receives, how can we see it?
2. Why can you often see colors in a diamond or in a cut-glass dish?
3. Find out how colored motion pictures are taken.
4. How do drops of water make a rainbow? Read the explanation in a physics book.
5. Study Figures 386 and 387. Explain how the glass in Figure 338 can show what is on the other side of the hill and yet not be a mirror.

LOOKING BACK AT UNIT 7

1. Write a list of what you consider to be the most important ideas in this unit.

2. What questions were answered in this unit that you wanted answered?

3. Show that you know the meaning of the following terms:

luminous material	*reflected light*	*opaque material*
transparent material	*angle of incidence*	*translucent material*
diffused light	*regularly reflected light*	*angle of reflection*
focus	*direct lighting*	*foot-candle*
indirect lighting	*convex mirror*	*semi-direct lighting*
image	*convex lens*	*concave mirror*
retina	*astigmatism*	*concave lens*
near-sightedness	*spectrum*	*far-sightedness*

ADDITIONAL EXERCISES

1. A yardstick held in a vertical position has a shadow eight inches long. A tree at the same time has a shadow ten feet long. How can you find out the height of the tree?

2. Examine a camera. Find out the purposes of the different adjustments. Make a report to the class.

3. Make a pinhole camera. Cut out one end of a pasteboard box and paste a piece of white tissue paper or tracing paper over this end. Bore a tiny hole, like a pinhole, in the center of the other end of the box. Set the box with the pinhole facing an open window. Throw a dark cloth over your head so that no light can get to your eyes except that which comes through the pinhole. What do you see on the tracing paper?

4. Suppose that you saw a fish in the water. If you threw a rock at the fish, how would you aim the rock? Explain.

5. Find out what a rapid or fast lens of a camera is, and how it is different from a slow lens.

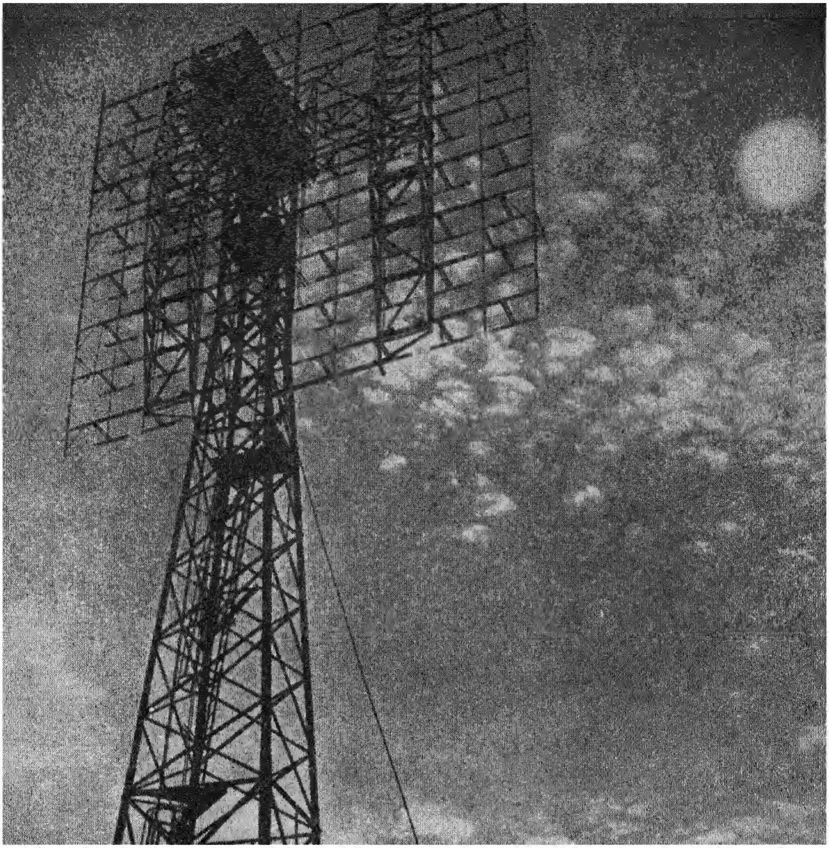


Fig. 390. From this queer-looking "bedspring" aerial on a hilltop in New Jersey a radar beam was directed at the moon January 10, 1946. Less than two and one-half seconds later sensitive instruments received a response. Traveling at a speed of 186,000 miles a second, radar waves hit the moon and bounced back to earth like an echo. They made the round trip of 470,000 miles faster than you can read about it. Radar, developed from radio, is one of the newest means of communication. Before scientists could work out modern methods of communication, they had to study sound. Then they had to discover how to change the energy of sound into electrical energy. (U.S. Army Signal Corps photo)

UNIT EIGHT

UNIT 8

HOW DO WE USE ELECTRICAL CURRENT?

INTRODUCTORY EXERCISES

*1. How does an electric flashlight produce light? Explain briefly how the electrical energy is changed to light energy.

2. What is inside an electric iron to make it get hot? Draw a diagram that shows how the wires are connected to the heating part.

3. What is a watt? A kilowatt?

4. Turn to Figure 408, page 454. Read the dial of the electric meter shown there. What number does it show? What units are indicated?

5. Explain why an electric bell rings when a button is pressed.

6. Make as long a list as you can of the different uses of electromagnets. Mark with a star the devices in which you have actually seen the magnet. Mark with two stars the ones you have used.

7. Explain briefly how an electric motor works.

8. What apparatus would you need to put a coating of silver on a brass spoon? Make a simple diagram to show how you would arrange the apparatus.

9. Most electric trains are provided with a rectangular box, called a transformer, from which wires go to an electrical "outlet" and to the track. What is inside the transformer case? What does it do?

10. Where in a telephone could you find a microphone? An electromagnet? What does each one do?

11. (*a*) Why does a radio set need "tuning"? (*b*) Why do most radio sets need an aerial? (*c*) Why does a radio set need an electrical current?

Fig. 391. When the sun goes down, millions of electric light-bulbs throughout our land begin to glow so that we can more fully enjoy the evening hours.

LOOKING AHEAD TO UNIT 8

In a fanciful story written centuries ago, Aladdin had only to rub his magic lamp to make a genie appear and carry out his wishes. Such stories have always been interesting, even though no one really believed they were possible. Yet, within the last hundred years the discoveries of scientists and inventors have put at our command a servant as powerful and mysterious as Aladdin's genie. In homes, factories, autos, and trains we need only to push a button to have almost unlimited energy obey our wishes. As you have already guessed, this servant is energy in the form of electric current.

The things electricity does for us make a long list. You have seen it at work in many ways. It floods our homes and streets with light during the night; it runs our machines, taking the place of much hard work and of clumsy steam engines; it keeps our food cool in one corner of the kitchen while it heats an iron in another corner; it sweeps the carpets and ventilates our rooms; it charges storage batteries, gives our metal-ware a covering of silver or

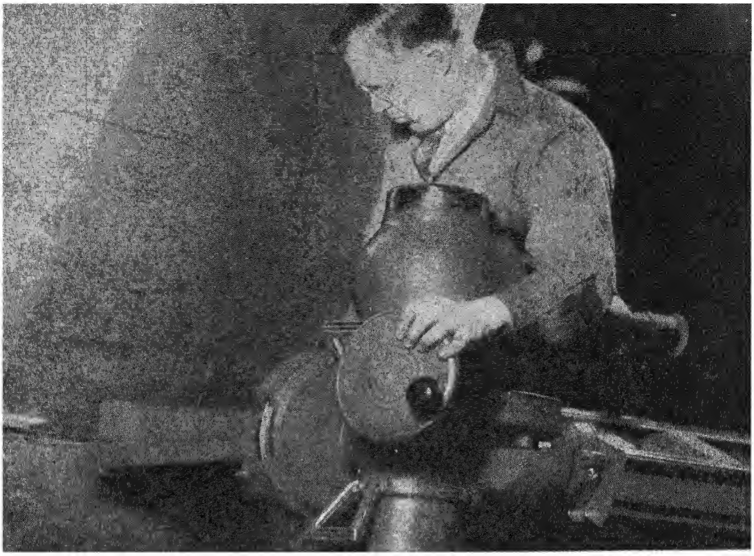


FIG. 392. This X-ray machine, which cannot be operated without electricity, takes a photograph that shows any hidden weak spots in the metal. (Westinghouse photo)

chromium, and produces chlorine to purify our drinking water. It brings us the voices of our friends, from across the ocean, if necessary; and more like a genie than ever, it catches mysterious messages from the air to fill our homes with music and to bring us the latest news.

Just to list all the things that electricity does may make it seem very mysterious to you. You may feel that it is much too strange and difficult for you to learn how electricity works in the many electrical devices that are all about you. However, in Unit 5 you learned that there are really only two important ways of producing electrical current. In the same way, when you begin to study how electricity works for you, you find that an electrical current can do only about four or five really different things. When you understand these few things, you can understand the uses of electricity reasonably well.

What are the important effects of an electrical current that we use? How does it make a motor turn? How can it

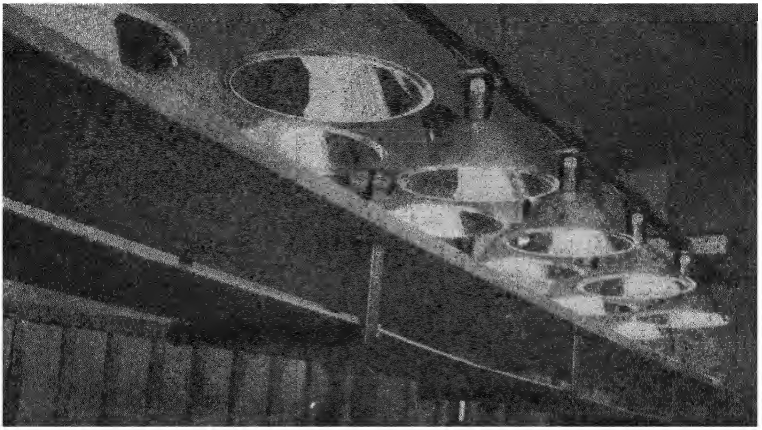


FIG. 393. Here the heat from electric bulbs is being used to dry paint. Freshly painted objects are placed on a moving belt that slowly passes beneath the bulbs. (Westinghouse photo)

heat an iron and cool a refrigerator? How does a telephone carry the sound of a person's voice? How does a radio catch messages from the air? What is television? What is a transformer? How can an induction coil make terrible shocks from a harmless dry cell? Why does an electric clock keep time? In this unit you will find answers to these questions and to many others.

Problem 1:
HOW DO WE GET HEAT AND LIGHT FROM ELECTRICAL CURRENT?

HOW DO ELECTRICAL HEATING DEVICES WORK? Of all the things operated by electricity, we are most familiar with those that produce heat. From some electrical devices we want light, but to get light we also make heat. Ordinary electric light-bulbs, irons, toasters, stoves, heating pads, arc lights, and electric furnaces all produce heat. They help us because they change electrical energy into heat. Let us first find out how irons and toasters work.

As you probably know already, every common heating device contains some kind of wire that becomes red-hot when the current is turned on. Why is it that the wires in these devices get red-hot, while the wires in the connecting cords do not?

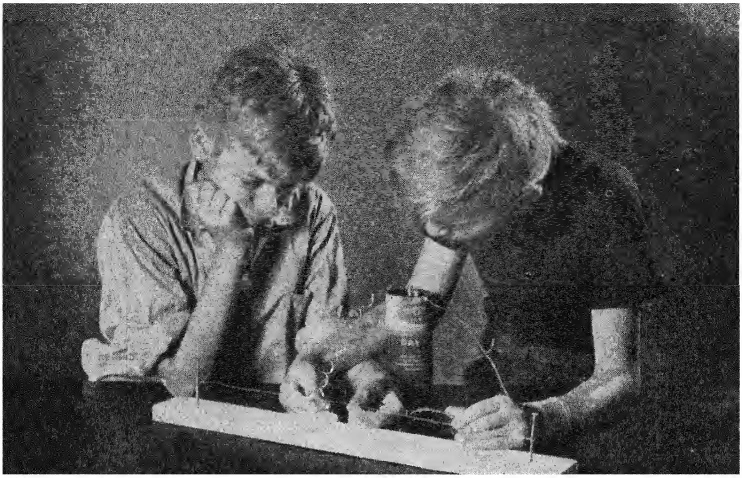


Fig. 394. Apparatus to show how electricity heats a wire

Experiment 40. *Under What Conditions Will a Dry Cell Heat a Wire Red-Hot?* Stretch a piece of fine (No. 30) bare copper wire two feet long between two nails driven in a board. Attach two pieces of larger insulated copper wire (at least No. 18) two feet long to the binding posts of a dry cell (Figure 394). Be sure the ends are scraped clean. Press the free and bare ends of the two insulated wires against the small wire near the ends. Have someone test the temperature of the small wire with his fingers.

Gradually slide the large copper wires closer together along the small wire. Notice that the small wire soon becomes hot where the electricity is flowing through it. After it becomes too hot to hold, continue to move the ends toward each other. Does the small wire become red-hot? Do the insulated wires become hot at all? Can you explain the difference?

To explain this you need to know a little about electrical resistance. In Unit 5 (page 279) you learned that every electric current heats its conductor. In all conductors the current meets a kind of electrical friction that is called *resistance*. Like all other friction, this resistance changes part of the energy into heat. Fortunately the heat produced in an inch of wire is usually so small that

we do not notice it. However, you found in your experiment that you could heat a small wire red-hot if you made it short enough. While the small wire became red-hot, the larger wires were slightly warm. The same current was flowing in both wires. Why did it heat one wire more than the other?

To understand this problem you need to know which wire has the more electrical friction or resistance per inch. In other words, is it harder for the electricity to get through an inch of small wire or an inch of large wire of the same material? Clearly, it is harder to get through a small wire; that is, the small wire has a greater resistance per inch. Therefore, a given electrical current makes more heat where the resistance is great than where it is small; so the small wire became hotter than the large wire.

But there is another problem to solve. Why did the small wire not get red-hot when the current went through a long piece of it? You can answer this question for yourself if you will think carefully. If the electrical pressure is kept the same, will more electricity flow through a long wire or through a short one of the same diameter? Through a short one, of course. The longer the wire, the more resistance there is. The resistance or electrical friction in the longer wire therefore allows less electricity to get through. When less electricity is flowing, less heat is made in each inch of wire. As you slid the two larger wires together, more and more electricity flowed through the small wire, until there was enough to heat it red-hot.

From this experiment you can remember three important facts: (1) When the same amount of electricity is flowing through several wires, the one with the most resistance will be heated most. (2) When much electricity is flowing through a wire, the wire is heated more than

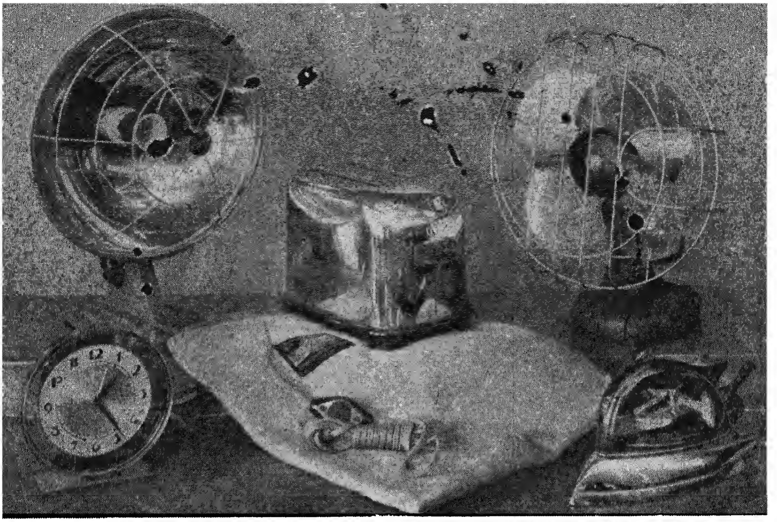


FIG. 395. Four common electrical heating devices are shown in this picture: a heater, a toaster, a heating pad, and an iron. The electric fan helps keep us cool, and the electric clock tells us the time of day.

when only a little is flowing. (A current twice as large as another really produces four times as much heat, while the same current passing through a resistance twice as large as another produces only twice as much heat.) (3) For each electrical situation there is a certain length of wire that will become red-hot or white-hot.

From these facts you can see how a designer goes about making a successful toaster, iron, or electric stove. He must first choose a suitable kind of wire for the electricity to heat. As you have seen, this wire should have a "high" resistance, so that for a current of given amount it will change much electric energy into heat. Different kinds of wire have different resistances, even though they are the same lengths and diameters. Table 2 gives the resistance of several metals and alloys (mixtures of metals) compared with silver. Silver has less resistance than any other common metal, although copper and aluminum are also very good conductors.

The wire chosen for heating must also have a high

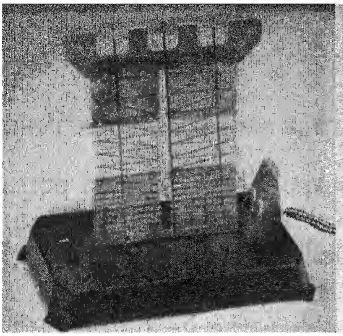


Fig. 396. The heating element in an electric toaster

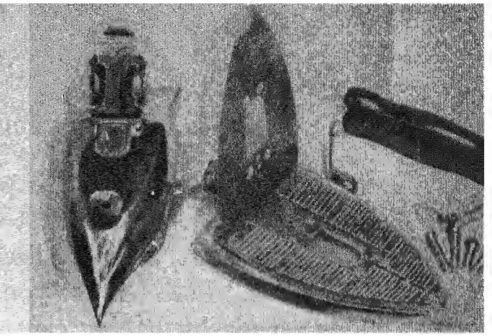


Fig. 397. The heating element in an electric iron

TABLE 2. Electrical Resistance of Some Common Metals Compared with Silver

Metallic Elements		Alloys Used in Electrical Devices	
Silver	1.00	Manganin	27.67
Copper	1.11	Constantin	30.82
Aluminum	1.78	Nichrome	62.89
Tungsten	3.52		
Iron (soft)	6.29		
Platinum	6.29		
Mercury	60.24		

melting point. This means that it must not melt when it gets very hot. Furthermore, it must not oxidize rapidly when it is heated. Some substances, like iron, would unite quickly with the oxygen of the air and break. The metals usually selected for "heating elements" are alloys of metals that have the right characteristics. When the designer has found a conductor with a high resistance to electricity, to melting, and to oxidation, he must then choose the right size and length of wire. You found in your experiment that the iron wire became red-hot when the battery current flowed through a certain length of it. To make an electrical heating device, a certain size and length of wire must be chosen. This can be learned by experimenting, or the designer can consult a table that tells him what size and length to use.

When he has the right length of heating wire, the designer coils it about some electrical insulator. The most

common insulators for this purpose are mica and porcelain. Mica is a mineral that splits into thin, transparent and somewhat flexible sheets. Sometimes it is called "isinglass." Porcelain, as you know, is a kind of artificial stone made by baking clay. When the heating wire, or heating "element," has been properly mounted on the insulating material, it is placed in the iron, toaster, or other heating device. Then the designer provides large insulated wires of some good conductor, like copper, to carry the electricity to the heating wire. When the current is turned on, the electrical current flows through the copper wires, but heats them very little. When it reaches the high-resistance wire, much heat is produced.

Self-Testing Exercises

1. What is electrical resistance?
2. Explain why the heating wire in an electric toaster becomes much hotter than the copper wires that bring the electricity to the toaster.
3. State three characteristics of a good material for the heating elements of electric irons.
4. A very small electric wire has a high resistance. Why could it not be used for heating an electric toaster?

Problems to Solve

1. A wire that is supposed to become red-hot does not do so when it is connected in an electrical circuit. State two changes that might be made to have the wire heat properly.
2. Why do you think most wires and transmission lines for carrying electrical current are made of copper or aluminum?
3. Examine as many electrical heating devices as you can to find out how the heating element (wire) is arranged in the space provided. What insulating materials are used in these devices?
4. Can you buy wires to put in electric heaters and toasters? Inquire at electrical, hardware, and ten-cent stores. If you can find some, try to learn of what metal or alloy they are made.

HOW DO ELECTRIC BULBS PRODUCE LIGHT? Today we use electric light-bulbs of many sizes, from tiny flashlight bulbs to the huge globes that illuminate airplane beacons and lighthouses. Some glow at an electrical pressure of only one or two volts. Others must have 6, 32, 110, or more volts to give light. Most of these bulbs use the principles you learned while you were studying about electric heaters. An ordinary light-bulb contains a wire that glows because it becomes white-hot, or *incandescent*. These light-bulbs are called incandescent bulbs. To be successful, the wire in a bulb must have the right resistance, it must not melt, and it must not oxidize or burn.

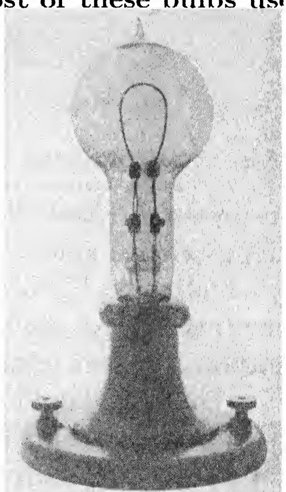


FIG. 398. Edison's first electric lamp

About sixty years ago (in 1880) Thomas Edison made the first successful incandescent light. For a wire, or *filament*, he used a small thread of carbon. Carbon does not melt or evaporate rapidly until it reaches a temperature above 5000° F. Thus it could be heated very hot without melting the filament. However, carbon burns rather easily. To prevent the filament from burning, Edison had it sealed inside a glass bulb. Then he pumped the air out and sent an electric current through wires connected to its ends. His plan worked, and manufacturers of electric light-bulbs have been using this plan ever since.

Edison's carbon-filament lamps had a number of disadvantages. The carbon filament used much electrical energy

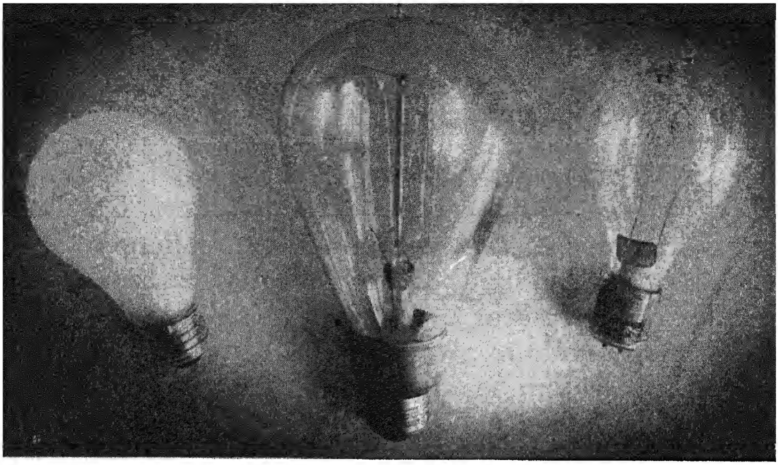


FIG. 399. At the right is an early kind of carbon-filament electric lamp. At the left are two modern tungsten-filament lamps, one of them with a frosted-glass bulb. (Westinghouse photo)

to produce a little light. In fact, about 99 per cent of all the electrical energy became heat instead of light. Thus, gradually the filament evaporated, and the carbon darkened the glass bulb. In spite of these disadvantages, carbon-filament light-bulbs were for thirty years the best that could be bought.

Today the filaments of our light-bulbs are made of tungsten. Each tiny tungsten wire is formed into a very close spring-like coil so that each turn of wire helps keep its neighbors hot. The glass bulbs are filled with the gas argon. Argon is a very inactive chemical element; that is, it does not combine easily with other substances. Therefore it does not change the tungsten. It is put into the bulb to keep the tungsten from evaporating as rapidly as it would in a vacuum. These improvements allow us to get seven times as much light from electricity as could be got with a carbon-filament bulb. But still we receive less than five per cent of the electrical energy in the form of light. Our light-bulbs are better heaters than "lighters."

Our city streets are filled with color by lamps of still another kind. These lamps are in the form of tubes that

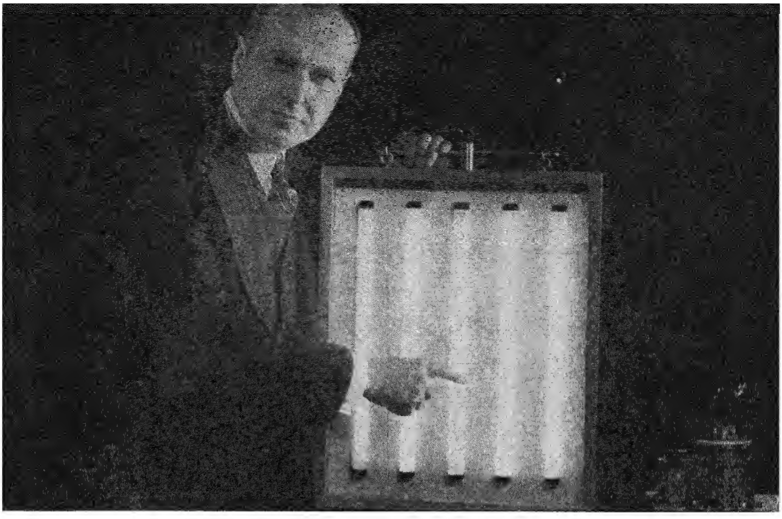


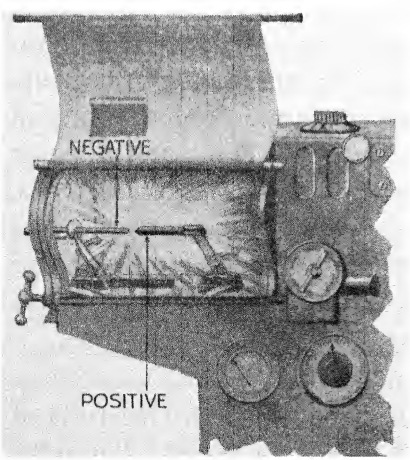
FIG. 400. This new kind of lamp, which has no filament, is called a *fluorescent* lamp. The glass tubes glow when current flows through a gas they contain. The insides of the glass tubes are coated with special materials. These materials make such a lamp give much more illumination for the same amount of current consumed by a filament lamp. Furthermore, when they are lighted, these fluorescent lamps are much cooler than filament lamps. (General Electric photo)

glow with red, blue, or green light when electrical current passes through them. The tubes are bent into all sorts of shapes to make attractive signs. We commonly call them "neon" signs, because the red ones really contain the gas neon. These "tube" lamps have no filaments at all. They contain very small amounts of gas. A special electrical transformer sends electricity through the gases with a pressure of thousands of volts. The electrons, striking the molecules of gases, cause the molecules to give out light. Each different gas gives out its own color of light. Figure 400 shows a fluorescent lamp, which gives more light with less heat than an incandescent lamp.

HOW DOES AN ELECTRIC ARC WORK? Have you seen or used one of the "sun lamps" that has two rods of carbon to make a very bright, "flaming" light? The light in a lamp of this kind is made by an *electric arc*. About

thirty years ago electric street lights were almost all arc lamps. Today electric arcs are used in sun lamps because they produce invisible ultra-violet rays. These ultra-violet rays are useful in curing certain diseases, but sometimes they are harmful. Electric arcs are also used in large moving-picture projectors and in one kind of electric furnace, called the *arc furnace*.

To form an arc, each carbon rod is connected to an electric wire, and the ends of the rods are touched together. When they become very hot, the rods are separated a fraction of an inch. The electric current continues to flow across the gap between the two rods. It flows in the carbon vapor that is formed when the carbon becomes hot. This vapor and the ends of the rods are heated to a terrific temperature and give out a brilliant light. It is so bright that one's eyes may be ruined by looking directly at the arc. To operate such a lamp an electrical pressure of fifty or more volts is usually needed. Arc lamps have clamps for holding the carbons and some kind of device for pushing the carbons closer together as they are used up. When connected to the ordinary house wiring, an arc lamp must also have a special device to prevent the "blowing" of a fuse when the ends of the carbons are touched together.



Electric-arc furnaces are used when unusually high temperatures are needed. Some very large ones are used to melt metal in steel

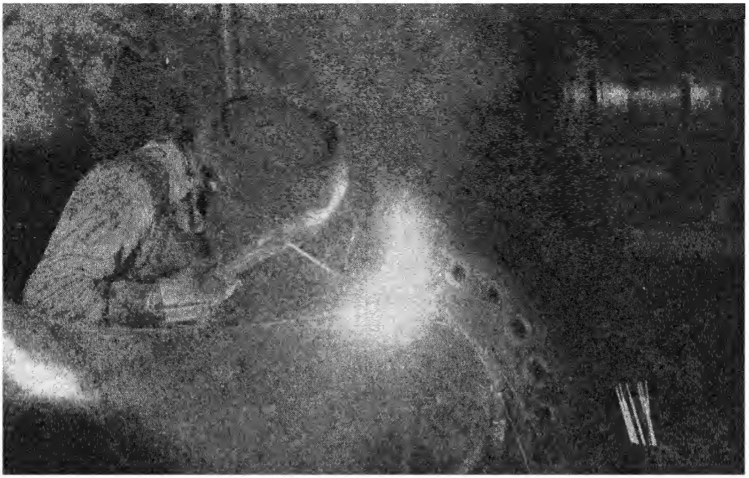


FIG. 402. So intense are the light and heat from an electric arc that men who do electric welding must wear masks with dark-colored glass in them. (Hedrich-Blessing Studio)

mills. In this kind of furnace two or three very large carbon rods reach down into the vessel that contains the steel or into a small insulated space where some material is to be heated. Electric arcs are also used for welding. One wire from the generator is attached to the metal to be welded. The other wire goes to a metal rod. The man who is doing the welding holds the rod in an insulated handle. He also wears a mask with a dark glass window to protect his eyes. He starts an arc by touching the end of the rod to the larger piece of metal. The intense heat melts the metal rod and also the metal along the joint that is to be welded. As the metal melts, the welder allows it to run into the joint and cool. Thus two pieces of metal are made into one by arc welding.

Notice that most heating and lighting devices produce heat and light because of the high resistance of an electrical conductor. When enough current passes through such a conductor, much electrical energy is changed to heat energy. If the conductor becomes hot enough, it gives out light, too.

Self-Testing Exercises

1. Draw a diagram to show how an incandescent light-bulb works. Show in your diagram the glass of the bulb, the filament, the connecting wires, and the vacuum or gas in the bulb. Label each part and tell what it does.

2. (*a*) What material was used for the first successful incandescent light-bulbs? (*b*) What material is used now? Why?

3. What is the main disadvantage of the electric light-bulbs we use most commonly?

4. Explain how a "neon sign" works.

5. (*a*) Tell how an electric arc is produced. (*b*) Name three important uses of electric arcs.

6. Must carbon rods be used for electric arcs? Why do you think your answer is correct?

Problems to Solve

1. Do you think the resistance of the gases in an electric arc is high or low? Give a reason for your answer.

2. Get a "burned-out" light-bulb. With a pair of pliers or other tools remove the base of the bulb. Find the wires that connect the base with the filament. How are they insulated from each other? Where is the tube that was used to pump the air out of the bulb? Wrap the bulb in a piece of heavy cloth, and break it to get a piece of the filament. Is it straight or coiled?

3. Read in reference books about one or more of the following: electric arc lamps, electric furnaces, Thomas A. Edison, electric lighting, electric heating, electric welding.

Problem 2:

HOW IS ELECTRICITY MEASURED?

YOU HAVE probably noticed that electricity flowing through wires acts much like water flowing through pipes. Like a water current in a pipe, any electrical current has a pressure that causes it to overcome the friction it meets as it passes through the conductor. It has also a certain rate of flow. And during any period of time, like a

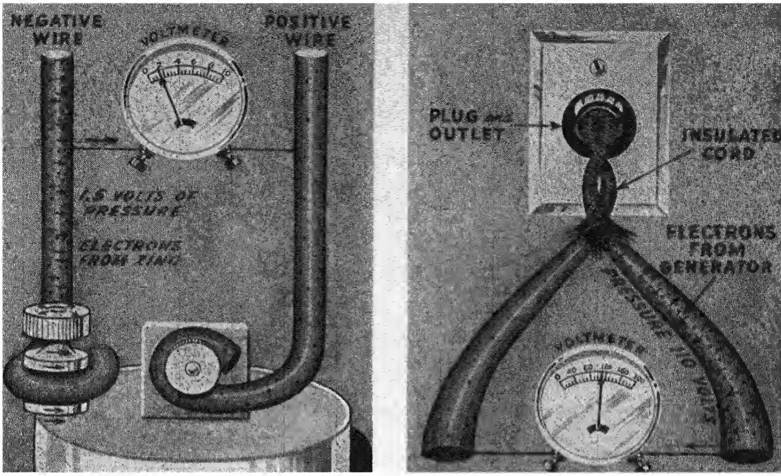


Fig. 403. A voltmeter is always connected between two wires that carry the current. What is the voltage in each circuit shown? If you can explain these drawings fully, you understand electrical pressure.

day or a month, we use a certain amount of electrical energy just as we use a certain amount of water from a water-supply system. To understand the use of electrical current, you need to know a little about how electricity is measured, just as you understand how water is measured. You need to know how we measure its pressure, its rate of flow, its power, and the amount of energy. When you know the electrical pressure and the rate of flow, you can calculate the power and the amount of energy used. Therefore, you need to learn about pressure and rate first.

HOW IS ELECTRICAL PRESSURE MEASURED? For your study of Unit 5, you needed to know a little about electrical pressure; so you became acquainted with the term *volt*, and you learned that the number of volts of electrical pressure tells how hard the electric current is being pushed into a wire. When you talk about water pressure, you speak of the number of pounds per square inch; that is, you may say the water inside a pipe is pushing against each square inch of the pipe with a force of forty pounds. In the same way the electricity in one wire

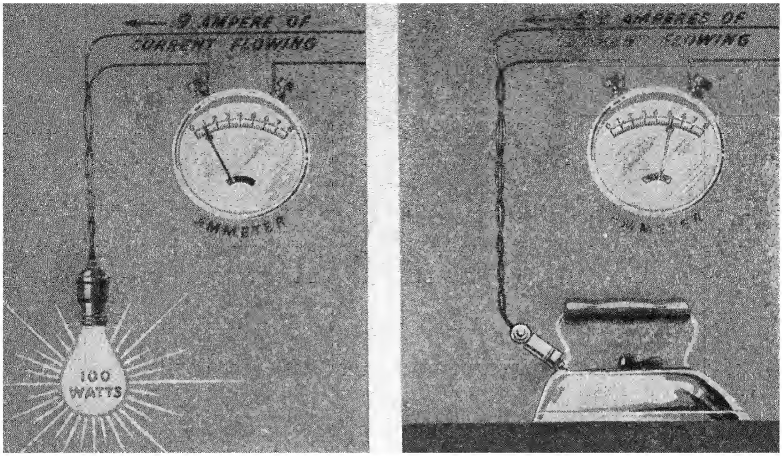


FIG. 404. An ammeter is connected into only one wire of the circuit. How many amperes are passing through each of these circuits?

of an ordinary house circuit may be trying to get across to the other wire with a force of 110 volts.

The instruments that measure electrical pressure are called *voltmeters* ("volt-measurers"). One kind of voltmeter has a small electromagnet on pivots between the poles of a horseshoe magnet. When a little electrical current is sent through the electromagnet, the electromagnet turns a short distance, but is held back by a spring. As the electrical pressure becomes stronger, more current goes through the electromagnet, and it turns farther. A pointer tells how many volts of pressure are at work. A voltmeter is always connected to the two wires between which the pressure is to be measured (Figure 403).

HOW DO WE MEASURE THE AMOUNT OF CURRENT THAT FLOWS THROUGH A CIRCUIT? In dealing with the flow of water we often need to know how much water is moving through a pipe or out of a faucet in a minute. When we have measured it, we say that the rate of flow is five gallons a minute, or in pumping water for a city it may be 60 million gallons a day. We measure the rate of flow of electricity, or the "size" of the current, in *amperes*.

Just as in the case of the volt, scientists have a very exact definition of an ampere of current. It is really a certain amount of electricity, a certain number of electrons, flowing through a wire in one second. But it will be better for you to remember that a "60-watt" light-bulb when lighted at a pressure of 110 volts has about .54 amperes of current flowing through it. A large electric iron requires about five amperes of current to heat it. With electricity at a pressure of 110 volts, a one-horsepower motor uses about 6.8 amperes of current.

The number of amperes flowing through an electrical circuit is measured by an *ammeter* (short for ampere meter). Probably the most common use of an ammeter is on the dash of an automobile to show whether the battery is charging or discharging. An ammeter is really made very much like a voltmeter, but it is connected to the wires in a different way. It is connected so that all the current that goes through the circuit goes through the ammeter. That is, it is connected in series with the device using the current (Figure 404).

Self-Testing Exercises

1. Make a table like the one below and fill in the blanks.

Water		Electricity		
What Is Measured	Units	What Is Measured	Units	Instruments
Pressure	Pounds per square inch	. . . .	. . . .	. . . .
Rate of flow	. . . .	. . . .	. . . .	. . . .

2. (*a*) What is the usual electrical pressure in the wiring of a house?

(*b*) State the approximate number of amperes of electric current used by at least two devices.

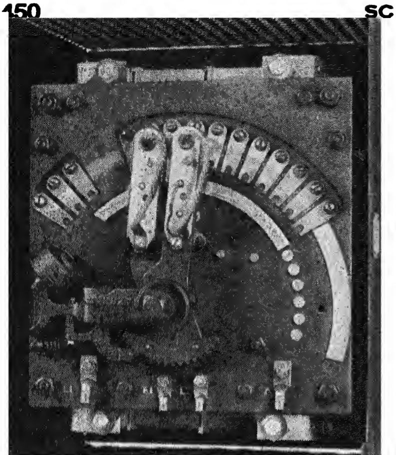


FIG. 405. *Rheostats* are used to regulate the speed of motors by regulating the strength of the current. This is done by increasing or decreasing the resistance in the circuit. The rheostat contains many coils of wire through which the current may flow. The greater the number of coils through which the current must flow, the less the current that can flow. By moving the arm of the rheostat to the right or left the current is made to pass through fewer or more of the coils of wire. Thus the resistance to the current of electricity is decreased or increased, and the strength of the current is regulated. (Westinghouse photo)

Problems to Solve

1. How do scientists define a volt? Look in an encyclopedia or physics book to find the answers to this problem.
2. How do scientists define an ampere?
3. Approximately how many amperes of current would be required by seven ordinary 100-watt incandescent lamps?
4. A fuse in a house-lighting circuit will melt and break the circuit if more than 15 amperes of current flow through it. A boy in the house turns on one 100-watt bulb after another. How many will he have on when the fuse "blows" (melts)?

HOW CAN WE FIND THE NUMBER OF WATTS AN ELECTRICAL DEVICE USES? As you know, electric light-bulbs, irons, and toasters, as well as many other electrical devices, have on them certain numbers that tell where they can be used and how much energy they will use. In addition to the voltage of the wires to which they should be attached, lamps are labeled 25, 60, or 100 watts. An electric iron is marked 575 watts; a waffle iron, 800. Just what do these labels mean? The number of watts

tells how fast an electrical device uses energy. If the device is a motor, the number of watts tells how fast it can do work. This is known as the power of the electrical current that is being used.

What connection do watts have with volts and amperes? When scientists chose the different electrical units—volts, amperes, and watts—they planned a very convenient relationship between them. The number of watts an electric iron uses is the number of volts of pressure multiplied by the amount of current that flows through it; that is,

$$\text{Watts} = \text{Volts} \times \text{Amperes}.$$

If an iron uses 5 amperes of current at 110 volts of pressure, the electrical power it uses is 5×110, or 550 watts.

When you know this relationship, you can use it to solve another kind of problem. For example, you know that a large light-bulb is labeled 300 watts. How many amperes of current flow through it when it is lighted? Remember that $watts = volts \times amperes$, or $300 = 110 \times$ the number of amperes. Divide 300 by 110, and you will find the number of amperes (2.7+amperes).

Self-Testing Exercises

1. What is the difference between a 500-watt motor and a 1000-watt motor?
2. If you know the number of amperes and the voltage used by an electrical device, how can you find the amount of power required to operate it (in watts)?
3. An arc lamp used 4.5 amperes of current at 110 volts. How much power did it use?

Problems to Solve

1. If you know the number of watts used by an iron and the voltage at which it works, how do you find the number of amperes that flow through the iron?

2. Find how many amperes are used by an 800-watt lamp at 110 volts.

3. How many amperes are used by a 575-watt iron made to operate at 32 volts? At 110 volts?

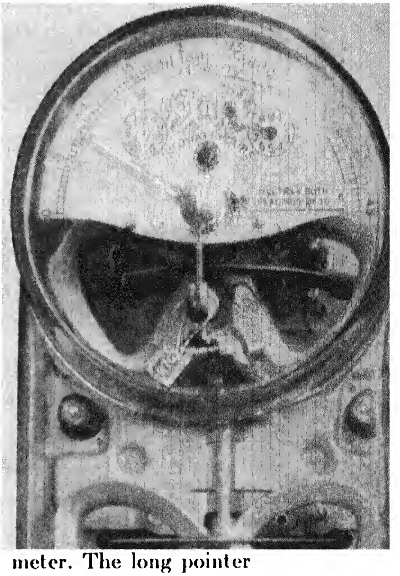
4. How many 60-watt light-bulbs can be lighted with the current needed for an electric iron?

HOW DO WE MEASURE THE ELECTRICAL ENERGY WE BUY? Near the place where the electric wires enter a building, you can usually find an electrical instrument. If you ask someone about this instrument, they will tell you it is an electric meter. Once each month a man comes to read the meter. He looks at the dials on the meter and puts a number down in the book he carries. Then a bill is sent from the electric company. This meter tells how much electrical energy has been used during the month.

However, you now know that there are at least two kinds of electric meters. One kind measures volts; the other, amperes. This meter must be a still different kind, for it measures the total amount of electrical energy that you use. Its face is also different from the face of a voltmeter or an ammeter. Instead of a single pointer that swings back and forth to show the amount or pressure of the electricity, there are several little dials, with hands like clock hands that turn very slowly (Figure 406). Under the dials you will probably find the words *Kilowatt-Hours*. And on the meter you can usually find the label *watt-hour meter*. You were right in thinking that this is a different kind of meter. Let us find out what it measures and how to read the dials.

To understand the meaning of a watt-hour, think a moment about driving an automobile. You can find out how far you have gone if you know two facts: (1) how fast you have driven, and (2) how long you have been

driving. That is, the total distance you have traveled is your rate of travel multiplied by the time you have been going. A problem of distance is easy to understand. And our electrical problem is almost as easy. The number of watts is the rate at which the lamps and irons use electrical energy.



meter. The long pointer indicates the greatest amount of current used at any one time during the month.

Let us turn on a 60-watt lamp. Electrical energy is being used at the rate of 60 watts. In an hour the lamp will have used a certain amount of energy. In two hours it will use twice as much, and so on. Scientists have agreed that the unit of electrical energy shall be the *watt-hour*. A watt-hour, as you can easily see, is the amount of energy that would be used by a one-watt lamp burning for one hour. How many watt-hours of energy would a 60-watt lamp use in an hour? Of course, it would use 60 watt-hours. In 24 hours it would use 24×60, or 1440 watt-hours.

You can see that a watt-hour is a rather small amount of energy. Even a small family would use a great many watt-hours in a month. Therefore scientists and engineers have decided to use a more convenient unit, known as the *kilowatt-hour*. One kilowatt-hour of energy is equal to 1000 watt-hours. The dials on electric meters tell how many kilowatt-hours of electric energy have passed through them. If there is a meter in your house, you will want to know how to read

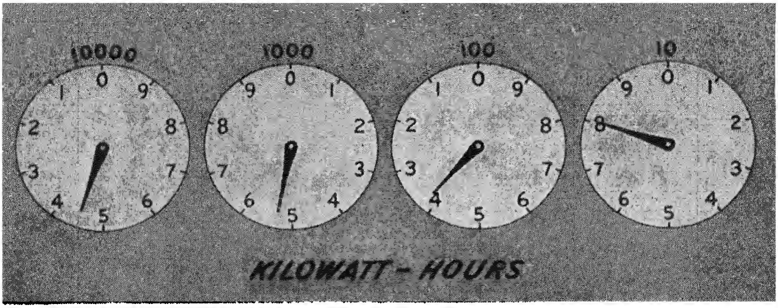


Fig. 407. The reading on these dials is 4538.

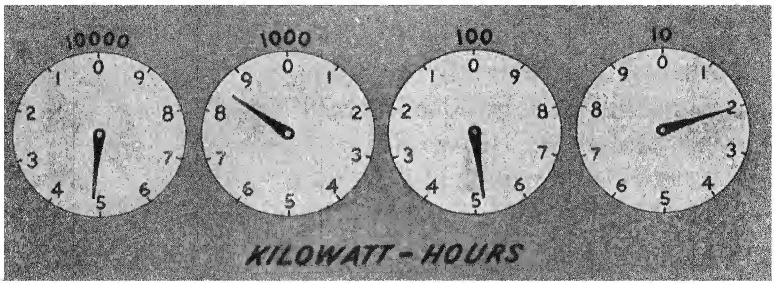


Fig. 408. The same dials as above, but a month later. What is the reading? How much electricity was used during the month?

it. If you can read it, you can tell whether your bills for electricity are correct.

Figure 407 shows the dials of a watt-hour meter. The pointer on the dial at the right makes one complete revolution while ten kilowatt hours of energy are being used. The dial second from the right makes one revolution for each 100; the third, one revolution for each 1000; and the fourth, one revolution for each 10,000. Therefore the reading is made by looking at the last figure passed by each pointer and by writing them down in the same order as the dials. Now answer the questions that are asked under Figure 408.

Self-Testing Exercises

1. What is a watt-hour? A kilowatt-hour?
2. An electric iron was used for three hours. The iron re-

quired 450 watts to operate it. How many watt-hours of energy did the iron use? How many kilowatt-hours?

3. How many watt-hours of energy would an 800-watt waffle iron use in one-half hour?

Problems to Solve

1. If a kilowatt-hour of electrical energy costs 5 cents, how much does it cost to operate a 60-watt lamp for 24 hours?

2. At the same rate how much was the cost of the ironing described in Self-Testing Exercise 2?

3. What is the rate charged for electrical energy in your community? Usually the rates will be given on the electric bills, or you can learn them by asking at the office of the company that supplies the electricity.

4. At the rates charged in your community, what should be the amount of the bill when two monthly readings were those shown in Figures 407 and 408?

Problem 3:
HOW DO ELECTRICAL CURRENTS DO WORK?

WHENEVER we think of electricity doing work, we think of electric motors. In homes electric motors furnish the force to sweep the floors, run refrigerators and fans, whip cream, mix cake, operate sewing-machines, and drive toy locomotives. On farms they grind grain, sharpen tools, milk cows, and pump water. They run all sorts of machinery in factories, stores, and pumping stations. They start our automobile and airplane motors and drive street-cars, electric locomotives, streamline trains, and ocean liners. Our country would be in serious trouble for a long time if all its electric motors should be destroyed.

Your main problem now is to find out how these important electrical machines are turned by electric current. However, you can better understand electric motors if

you have a clear idea about such simple devices as electromagnets and electric bells. Let us see how the usual kind of electric bell works.

HOW DOES AN ELECTRIC BELL WORK? The heart of the usual kind of electric bell is a double electromagnet. As you probably know, all that is needed to make an electromagnet is a soft iron bar and some insulated wire.

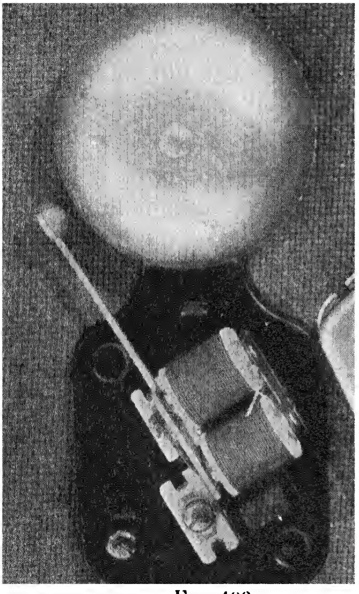


FIG. 409

When the wire is wrapped around the bar and electrical current is sent through the wire, the bar becomes a magnet. The poles, the strongest parts of the magnet, are at the ends of the bar. To make an electric bell, the arms of a U-shaped piece of iron are wrapped with insulated wire. Thus the poles are near each other, and both can pull on the same piece of iron or steel. Furthermore, the wire is wrapped around the magnet in such a way that one pole is a north-seeking pole, and the other is a south-seeking pole. This makes their pull on a piece of iron even stronger. (If you are not sure as to exactly how magnets act toward each other, see *Science Problems, Book 1*, Unit 7.)

In the electric bell (Figure 410) a soft iron bar, or *armature*, stands just a little distance away from the poles of the electromagnet. This armature is fastened to a spring. The armature also carries two other pieces of metal. One is the clapper for the bell. The second is a little contact point that touches another contact point on the base of the bell.

Now let us suppose that everything is connected as shown in Figure 410. You press the button. The dry cell sends electricity through the electromagnet. Almost instantly the armature and the clapper attached to it are pulled to the left. The clapper strikes the bell and makes it ring. But something else happens at the same time that the clapper strikes the bell.

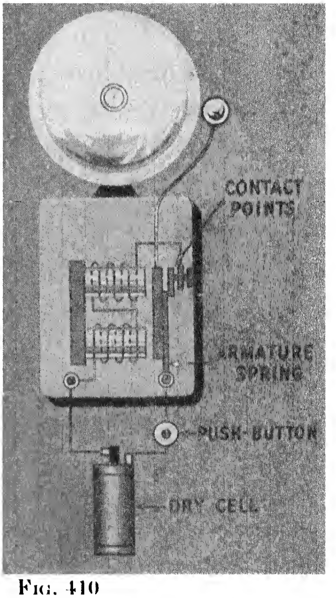


FIG. 410

When the clapper is pulled to the left, the contact point on the armature pulls away from the contact point that is fastened to the base of the bell. This breaks the circuit and shuts off the current. Therefore the magnet loses its strength and can no longer hold the armature. Then the armature is pulled back by its spring. When this happens, the contact points touch again, the magnet pulls on the armature, the clapper strikes the bell, and the whole process is repeated over and over again so long as you press on the button. It is hard to believe that the electromagnet can pull and let loose as rapidly as the clapper strikes the bell, but you know that it does. And the electric buzzers that you may have heard work in the same manner that electric bells work.

From this description of an electric bell you can understand how an electromagnet is made. Of course, most electromagnets are not turned on and off as rapidly as those in bells and buzzers. The electromagnets in most motors are magnetized all the time the motors are running.

Self-Testing Exercises

1. Tell briefly how an electromagnet is constructed.
2. Why does the clapper of an electric bell fly over and hit the bell when the push-button is pressed?
3. Why does the clapper not remain pressed against the bell so long as the button is held down?

HOW DOES AN ELECTRIC WIRE ACT NEAR A MAGNET? To understand how a motor works, you will need to know how a wire carrying a current acts when it is in the *magnetic field* between the poles of a magnet. You will want to see for yourself this strange action of the wire.

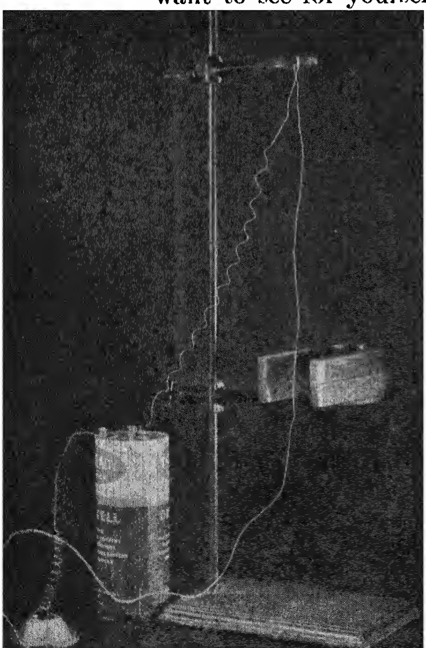


FIG. 411. Apparatus for Experiment 41

EXPERIMENT 41. *How Does an Electric Wire Move in a Magnetic Field?* (*a*) Arrange a strong U-magnet, a dry cell, a push-button, and a length of No. 30 insulated wire as shown in Figure 411. Be sure the wire is loose and free to move. Press the button. What does the wire near the magnet do? Release the button and repeat the experiment to make sure you were correct. *b*) Now change the wire so that the current goes through it in the opposite direction. Press the button again and notice what the wire does.

From this experiment you realize the truth of a law discovered a long time ago by Michael Faraday: *A wire carrying a current tends to move when the wire is in a magnetic field.* The full statement of the law tells

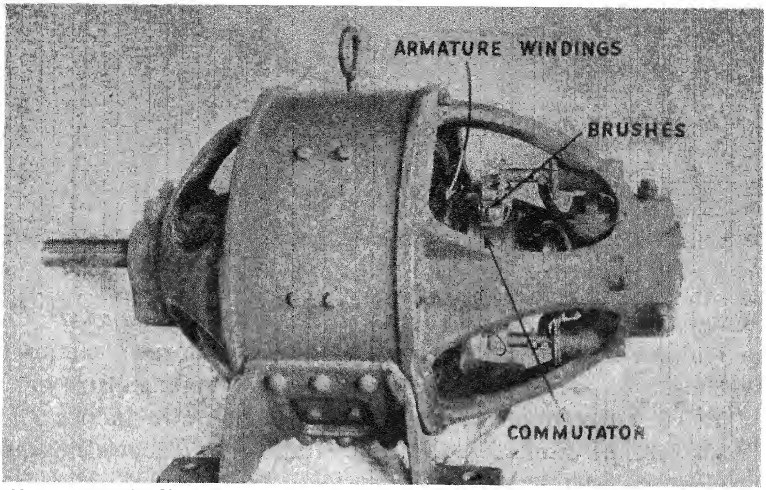


FIG. 412. A direct-current electric motor. *Armature windings* means the thousands of feet of wire that are wound around a core to make the armature. (Westinghouse photo)

just which way the wire moves in the magnetic field. But all you need to know is that the wire moves in one way when the current flows in one direction and in the other way when the direction of the current is reversed. When you know these facts, you can understand why an electric motor can be made.

HOW DOES AN ELECTRIC MOTOR WORK? Each electric motor has two important parts, the *field magnets* and the armature. As you can guess, the field magnets are needed inside the motor to make a strong magnetic field. Just as in the bell, the armature is the part of the motor that moves. Small motors of the kind that you can make easily have two other parts, the *commutator* and the *brushes*. Acting together, the commutator and the brushes carry current to the wires on the armature. The generator that you studied in Unit 5 had a commutator and brushes to carry current from its armature to a circuit outside the generator. If you are reasonably careful, you can make a small electric motor that will really run, as described in Experiment 42, on the next page.

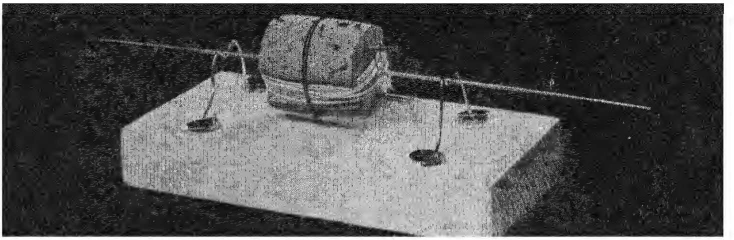
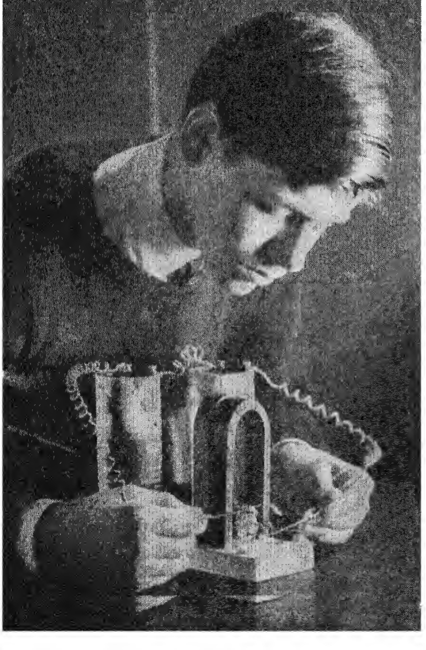


FIG. 413. Armature of a home-made motor

EXPERIMENT 42. *How Is an Electric Motor Constructed?* For the field magnets of your motor use one or two large U-magnets like those you used in Experiment 41. For the armature get a cylindrical cork or piece of soft wood about two inches long and an inch in diameter. Cut two shallow lengthwise notches on opposite sides of the wood or cork cylinder. Wind about twenty turns of No. 22 or No. 24 insulated wire in these notches (Figure 413). Tie a thread around the middle of the cylinder over the wires to hold them in place.



Now cut two small pieces of No. 18 bare copper wire about an inch long, or get two nails about that size. Push them into the cylinder at the points shown in Figure 413; fasten one free end of the wire to each bare wire (or nail). Get a large needle or two nails for the shaft and some bent wires for bearings. The armature will work better if it is balanced so that it will stand in any position.

Place the field magnet (or magnets with N-poles together) over the armature, as shown in Figure 414. Set the armature coil horizontal. Connect copper wires to one or two dry cells, uncover the ends, and hold them as shown in the figure. When the wires from the cells touch the wires on the armature, the armature should start turning

and continue until you remove the wires. Sometimes it may be necessary to have someone give the armature a turn to start it. You may need to practice a little to learn just how to hold the wires. With a little thought you can probably work out a way of fastening the connecting wires on nails or screws so that you will not need to hold them.

In a home-made motor like the one shown in Figure 413, the "pins" to which the armature wires are fastened make the commutator. The wires held in the hand are the brushes. Let us see why the motor starts turning and continues to turn. The reason for its starting is easy to see. The wires of the armature coil act just like the wires in Experiment 42. The electric current going in one direction in all wires on one side (at A in Figure 415) causes that side to be pulled upward through the magnetic field. The same current going in the other direction on the other side of the coil causes that side to be pulled downward. Thus the coil starts to turn.

current operates the home-made motor

But just as the armature gets a good start, the commutator pins move away from the brushes. Inertia keeps the armature turning until the pins strike the brushes again. Now the "pins" are reversed, and side A, which was pulled upward, is pulled downward. Side B, which was pulled downward, is pulled upward until the "pins" leave the brushes again. Then the whole process is repeated for every revolution of the armature.

One trouble with your toy motor is that it does not pull steadily. When the wires are at the top and bottom, they cannot pull. You could improve it by adding another coil at right angles to the first (Figure 416), or even three coils evenly spaced around the cylinder. Then at least one set of wires would be pulling all the time. Another improvement would be to make the commutator in the form of a smooth ring cut into pieces, as shown in Figure 417. Then the brushes would slide smoothly along and be touching the commutator all the time while it is whirling around.

Modern electric motors use all these ways of improving the armature. The wires are wound on the armature in such a way that all the wires on one side are always pulling up, and all those on the other side are always pulling down. The wires or windings on the armature are connected in a complicated way with many pieces of a smooth commutator.

Another way of improving a motor is to use powerful electromagnets to form the magnetic field. The poles of these magnets are set very close to the metal armature. In this way the magnetic field inside the motor is made very strong. In some motors that must pull very hard, there may be a double set of field magnets (four poles).

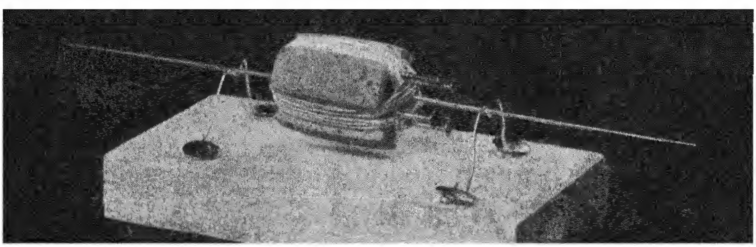


FIG. 416. A better armature for the home-made motor

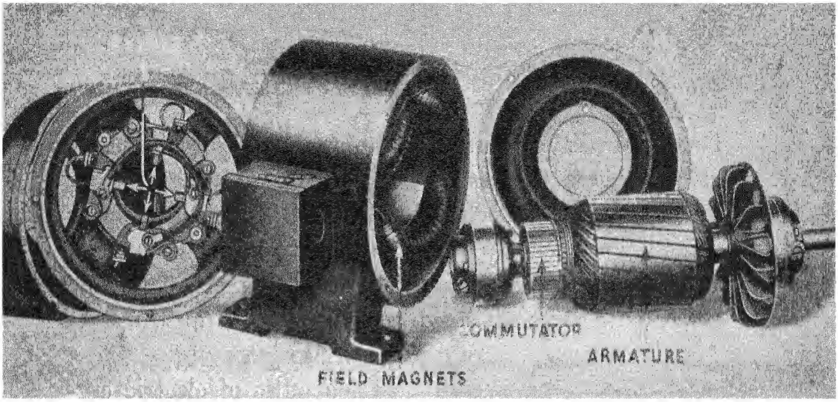


FIG. 417. Parts of a motor to show brushes, field magnets, commutator, and armature (Fairbanks Morse photo)

as shown in Figure 417. Then there are four brushes instead of two touching the commutator and four sets of wires pulling constantly. These improvements and many others that we cannot describe here have made electric motors very efficient. The best motors change about 90% of the electrical energy they use into kinetic energy for doing work. Motors of many different sizes and kinds are made. Some of our smallest motors drive electric clocks. At the opposite extreme in size are the motors used to drive ocean liners. Some of these giants have 40,000 horse-power.

Some motors will run only on *direct current,* that is, current that flows in one direction all the time. Others will run on both *alternating,* or reversing, current and on direct current. Still others will use only alternating current. Some motors of this last kind, called *induction motors,* are most mysterious. The armature has no commutator, no brushes, and no electrical connections from the outside at all. Yet it turns with great force.

Another queer kind of motor keeps in perfect step with the generator that is supplying it with current. Such a motor is called a *synchronous* ("timed-with") motor.

One kind of synchronous motor is used to drive electric clocks. These motors use 60-cycle alternating current, that is, current that changes its direction 120 times every second. Thus each second there are 120 separate pulses of current. The armature and the field magnets of a clock motor both have small projections, or teeth on them, as shown in Figure 418.

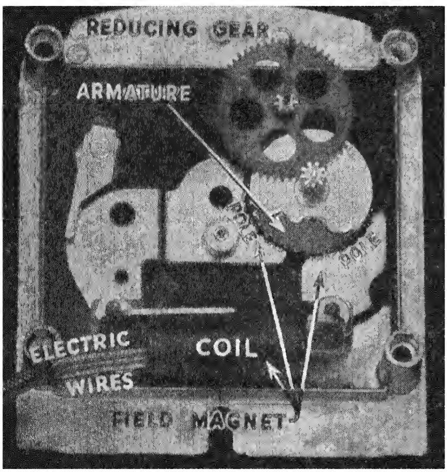


FIG. 418. How a synchronous electric clock works

Each pulse of electric current pulls the nearest teeth of the armature toward the teeth of the magnets. Then there is a moment of no pull while the teeth pass each other. The next pulse pulls the armature teeth to the magnet teeth one notch farther on. Thus for each pulse in the current each armature tooth passes one magnet tooth. The generators at the power-houses are regulated to send out exactly 120 pulses each second on the average. Thus electricity is used to help us keep very good time, and our electric clocks never need winding.

Notice that electric motors do not actually harness natural energy. They are part of a system for transmitting energy from power machines to working machines. Energy harnessed by a water-wheel, for example, turns a great generator. In the generator the kinetic energy of the falling water is changed into the energy of an electrical current. This current then passes through wires to a motor. The motor changes the electrical energy of the

current back into kinetic energy again to do work by running machines of all kinds.

Self-Testing Exercises

1. What does a wire in a strong magnetic field do when an electrical current is sent through the wire? When the current is sent in the reverse direction?
2. Why does an electric motor need to have field magnets to make it run?
3. Explain why the armature of an electric motor turns when electrical current is sent through it.
4. Why are brushes and a commutator necessary in most electric motors?
5. What is a synchronous motor?
6. Why are electric generators and motors very useful?

Problems to Solve

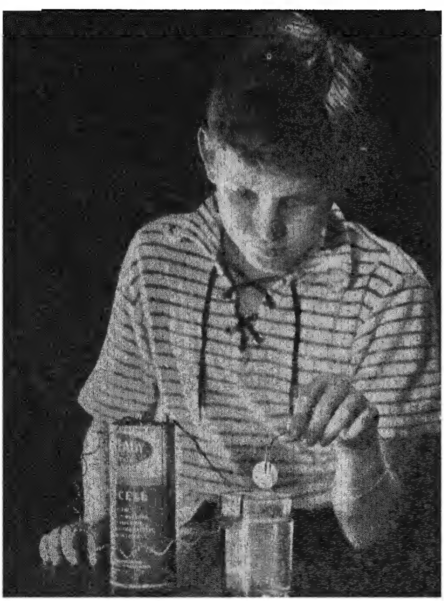
1. Why do the armatures of most electric motors have several coils of wire on them?
2. Why are there many wires in each coil?
3. What advantage can you find for using electromagnets rather than permanent magnets in motors?
4. Find an electric motor that you can examine. Locate each important part named in Problem 3.
5. Electric motors run very rapidly. What ways can you find for slowing down the movement they produce; that is, how could you make a machine attached to a motor run more slowly than the motor? Think of what you learned about simple machines.
6. Make a diagram to show how the field magnets and armature of a motor could be connected so that both armature and field magnets would receive current from one pair or wires. Does your plan connect them in series or in parallel? Is the other plan possible?
7. Read in reference books to find how an *induction motor* works without brushes and a commutator.

Problem 4:

HOW IS ELECTRICAL CURRENT USED TO CAUSE CHEMICAL CHANGES?

HOW IS ELECTRIC CURRENT USED FOR PLATING? One of the important characteristics of electrical current is that it can make chemical changes take place in certain kinds of solutions. Chlorine and lye are made by means of electrical currents, and electrical current separates aluminum from its ore and plates copper, silver, nickel, and chromium on all kinds of articles. You can understand the process of electroplating best by doing some of this kind of plating yourself.

EXPERIMENT 43. *How Is Copper Plating Done?* Make a rather concentrated solution of copper sulphate in water. Add a few drops of sulphuric acid to the solution and put it in a glass tumbler or a beaker. Get a strip of copper. Clean a silver coin thoroughly with soap and a brush; then rinse it in clear water. Without touching the coin with your fingers, slip it in a paper clip.



Hang the paper clip on the end of a wire attached to the negative (zinc) electrode of a dry cell (Figure 419). Connect the positive (carbon) electrode to the copper strip. Then lower both coin and strip into the solution without allowing them to touch each other. After a few minutes lift out the coin. What has happened? (You can remove the copper from the coin by reversing the connections to the dry cell.)

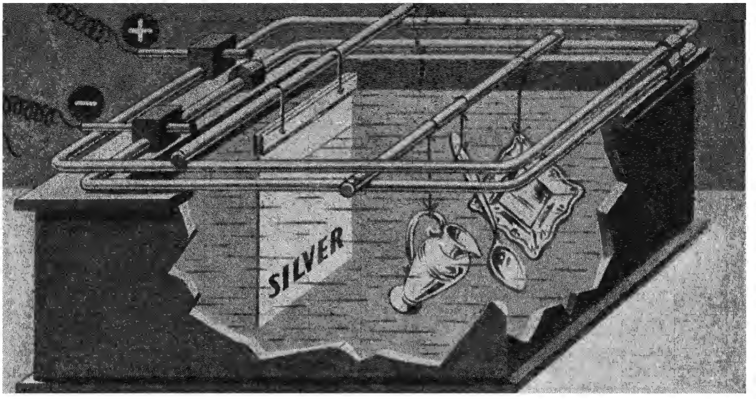


Fig. 420. This drawing will help you understand how an electroplating tank works.

From this experiment you can see how all electroplating is done. The solution, or *electrolyte*, must contain a compound of the kind of metal that is to be plated on the object. To plate gold the solution must contain a compound of gold. To plate silver the solution must contain a compound of silver, and so on. The article to be plated is suspended in the electrolyte and connected with the negative wire from a direct-current generator or cell. A strip or bar of the kind of metal to be plated is also suspended in the electrolyte and is connected to the positive wire. When the current is turned on, metal from the solution is deposited upon the article being plated, and metal from the positive plate dissolves in the electrolyte. In this way the metal taken from the solution is replaced by metal dissolving from the positive plate.

This book was printed from plates made by electroplating. This is done as follows. The page is first set up in type. Then a mold of the type is made by pressing it into wax spread on a plate of copper. The mold impression is removed and covered with a thin layer of powdered graphite. The graphite is added to the wax to make it a conductor of electricity. This wax mold on its copper plate is suspended in an electrolyte of copper sulphate,

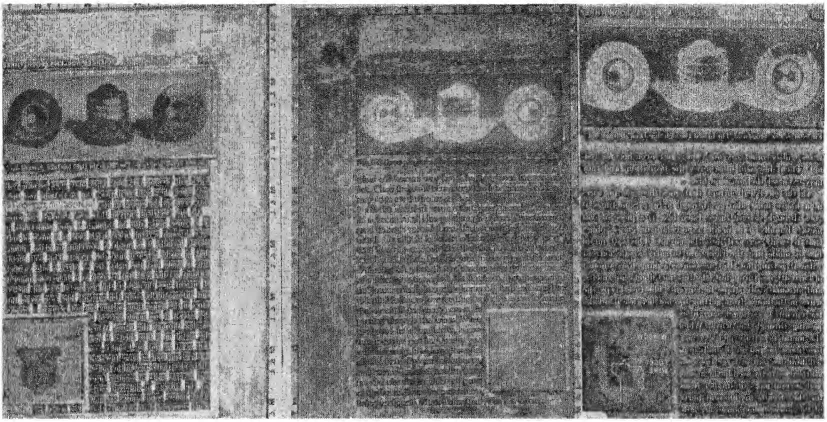


Fig. 421. At the left is the type from which page 280 of this book was made. Next to it is the wax mold of the same page. Notice the position of the type and the illustrations in the wax mold. At the right is the printing plate.

and the current is turned on. After copper of the desired thickness has been deposited on the mold, the mold is lifted from the electrolyte, and the thin copper sheet is pulled from the mold. This thin sheet is then made strong by pouring melted lead on the back of it and allowing the lead to harden. This forms the printing plate.

How is an electric current used to separate compounds and purify metals? When you first learned about elements and compounds, you probably found it hard to believe that water is made of two colorless gases, oxygen and hydrogen. You had to accept without proof the statement that chemists had taken water apart, or decomposed it, and found what it is made of. Now, however, you can do this experiment and prove for yourself that water is a compound of two gases.

Experiment 44. *How Is Water Decomposed?* You can do this experiment most easily with an electrolysis apparatus (Figure 422), which may usually be obtained from the physics or chemistry laboratory. However, you can make a simple electrolysis apparatus like the one that is shown in Figure 423.

Get a round half-gallon bottle and cut it in half. Obtain

two strips of carbon and fasten each to a copper wire. (Strips of carbon may be obtained from old flashlight batteries.) Push the other ends of the copper wires through a cork that fits the bottle (Figure 423). Fill the bottle with water containing a little sulphuric acid (about one part to each 40 parts of water). Then fill two test-tubes with the acid water and place one of them over each carbon electrode. Attach one wire to the positive side of a battery of from one to six dry cells in series, and the other side to the negative side of the battery.

Observe the bubbles of gas rising in the tubes. Is there the same amount in each tube? When the first tube is filled, place your thumb over the bottom of it and remove it from the bottle. Bring a lighted match to the end of the tube. What happens? This gas is hydrogen. Test the gas in the other tube with a glowing splint. What happens? This, as you know, is a test for oxygen.

If absolutely pure water is used in this experiment, together with a known weight of sulphuric acid, a chemist can show that the weight of the hydrogen and oxygen equals the weight of the water that disappears. The weight of the sulphuric acid does not change. It is used to make the water a conductor. The hydrogen and oxygen, therefore, must

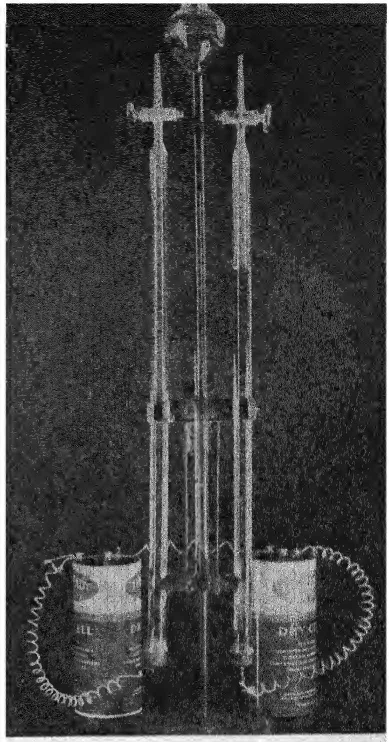


Fig. 422

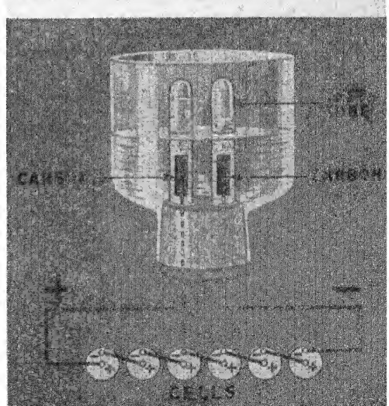


Fig. 423

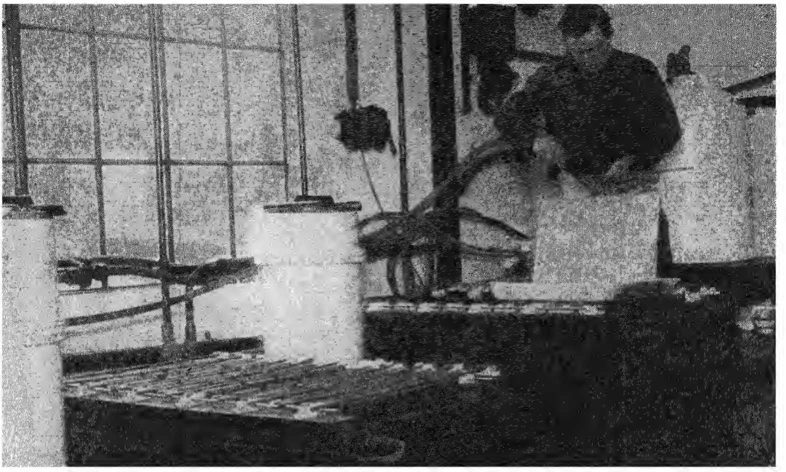


FIG. 424. This workman is scraping crystals of silver from an electrode on which it has been deposited by electrolysis. (Wide World photo)

have been produced by the decomposition of water. This process is called *electrolysis*.

Electrolysis is a very common commercial process. Hydrogen and oxygen are both prepared extensively by this method. Chlorine, a greenish-colored gas used to bleach cloth and to purify water, is made by this method. Another use of electrolysis is to free certain metals from their ores. One of the most important metals obtained by this process is aluminum. Aluminum was first made in 1825, but the process was so expensive that the metal was just a rare curiosity. It cost about $160 a pound to make it. In 1886, Charles Hall, a young chemist who had just graduated from Oberlin College, in Ohio, discovered how to obtain aluminum by electrolysis from some of its melted compounds. This one discovery made it possible to produce aluminum for a few cents a pound.

By this time you are probably wondering how the chemical action in electroplating and electrolysis is brought about by passing an electric current through a solution or through melted compounds. Later on in your study of science you will find out the details of this

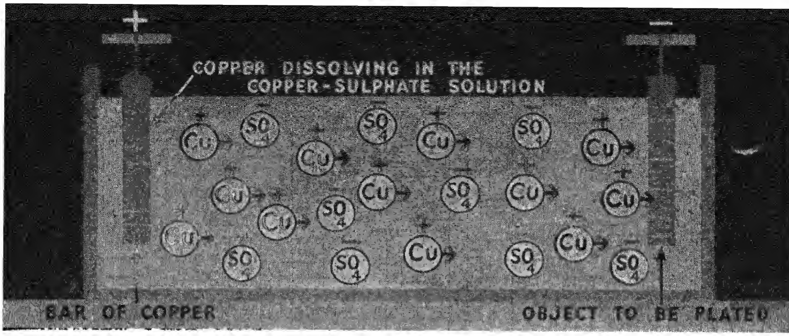


FIG. 425. Why objects can be electroplated

process, but this is an outline of what happens: Certain compounds seem to be made up of small particles, called *ions*. These ions have electrical charges. Copper sulphate, for example, breaks up into two kinds of ions—copper ions with positive charges and sulphate with negative charges.

In your experiment with electroplating you remember that the object to be plated is connected with the negative side of the battery. The positively charged copper ions are attracted by the negative charge on the article and move over to the object. When they touch the object, they take electrons from it and become ordinary copper atoms. These copper atoms form a layer of copper metal on the object to be plated. Electroplating and electrolysis vary with the kinds of materials used, but they always depend upon the formation of charged particles, or ions, that are attracted by one of the electrodes.

Self-Testing Exercises

1. How is electroplating done?
2. How is a printing plate made for a book?
3. In electroplating, to which side of the battery should you always attach the object that is to be plated? Why?

Problems to Solve

1. Why cannot alternating current be used in electroplating?
2. Does the hydrogen come off the positive or negative electrode in the electrolysis of water? What does this show you about the electrical charge of the hydrogen ions?

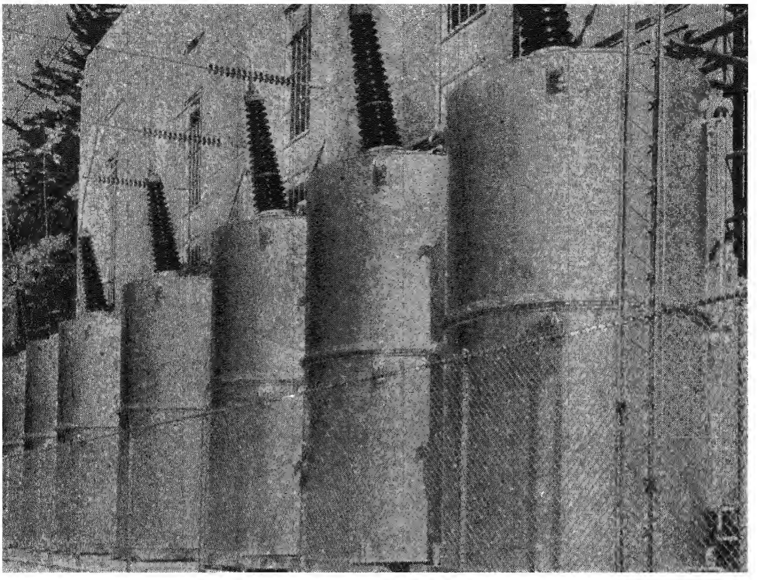


FIG. 426. Step-up transformers at the Diablo Power Plant on the Skagit River, Washington. The generators at this plant generate electricity at a pressure of 13,800 volts. These transformers raise the pressure to 222,000 volts before it is sent over the wires to the city of Seattle. (Westinghouse photo)

Problem 5:

HOW IS ELECTRICAL ENERGY TRANSMITTED TO OUR HOMES?

WHAT PROBLEMS MUST BE SOLVED IN TRANSMITTING ELECTRICAL ENERGY? We are so accustomed to using electricity whenever we need it that we often pay little attention to where it comes from. You may not know, for example, where the electricity you use is produced. Many towns and cities get their electricity from power plants in or near the town. Some cities, however, obtain their electrical energy from power plants located hundreds of miles away, where there are natural waterfalls or where power dams have been built in rivers. Los Angeles, for example, obtains some of its electricity from a water-power plant in the Sierra Nevada Mountains, 250 miles away. Rochester and Syracuse, New York, obtain their electricity from generators at Niagara Falls.

In traveling across the country you have probably seen the tall steel towers that support cables of copper or aluminum through which the electricity is transmitted. These cables are attached to huge insulators that keep the electric current from leaking off into the ground. If you ever stopped to examine one of these towers more closely, you probably saw a sign, "Danger—100,000 Volts" or "Danger—High Tension Wires."

If electrical wires come to your home, you probably know that the current you use has a pressure of about 110 volts. When electricity is transmitted for long distances, it is necessary to use a much higher voltage. Let us see why. First of all, the longer the conductor, the greater the resistance offered to the passage of the current. A larger electrical pressure is therefore needed to force the current over long distances than over short distances. Second, you will remember that in overcoming this resistance a part of the electrical energy is changed to heat energy. This energy is, of course, lost. Third, you remember that the greater the amount of current flowing through the wire, the greater the amount of electrical energy that is changed to heat.

The problem of the electrical engineer is to transmit the electrical energy with as little loss as possible. To reduce the amount of electrical energy changed to heat, it is necessary to keep the amount of current as low as possible. You will remember that the power as measured by watts is equal to the volts times amperes (page 451). To keep the amount of current low and still get the same power, it is necessary to increase the voltage. For example, with a voltage of 200 and an amperage of 100 the total amount of power transmitted is 20,000 watts. A voltage of 20,000 and a current of 1 ampere will also transmit 20,000

watts. But in the second case only $\frac{1}{10,000}$ as much energy will be lost. By keeping the voltage high and the amount of current low, only a very small amount of electricity is lost by being changed to heat.

The second problem of the engineer is that of securing the high voltage necessary for long-distance transmission of power. The generators used at Niagara Falls produce electricity at a pressure of 12,000 volts. Too much current would be lost in transmission over long distances at this voltage; so the current is changed by raising it to 60,000 volts before it is sent out over the transmission wires. How is this done?

HOW DO TRANSFORMERS CHANGE THE VOLTAGE OF A CURRENT? The device used to change the voltage of a current is called a *transformer*. You have probably seen a black box on one of the electric-light poles near your home. In this black box is a transformer (Figure 427). Traveling through the country you may have seen the transformers used for long-distance transmission of electricity. The small black box used to operate an electric train also contains a transformer.

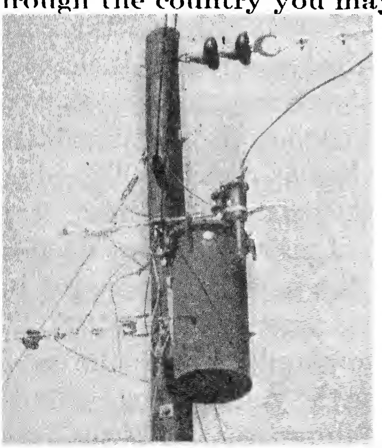


FIG. 427. A pole transformer (Westinghouse photo)

To understand how a transformer works, you will need to recall what you learned about the operation of a dynamo. In Experiment 42 we saw that a current was produced when a coil of wire was rotated between the poles of a magnet. When this was done, the coil

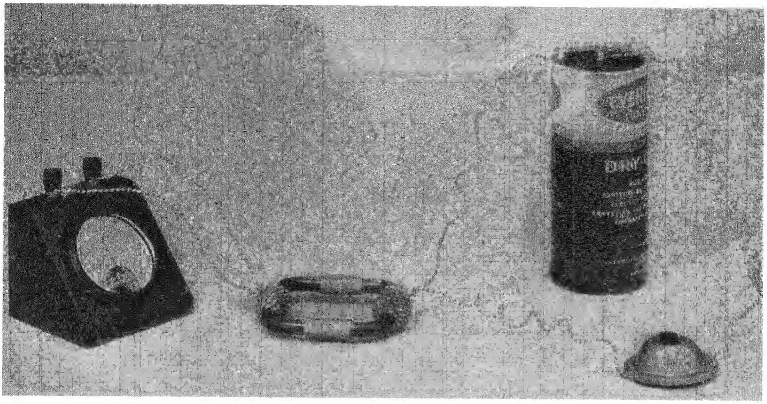


FIG. 428. Apparatus for Experiment 45

of wire cut across the lines of force between the poles of the magnet. When the coil was stationary, no current was produced. The same idea is used in making a transformer.

EXPERIMENT 45. *How Is a Transformer Made?* Obtain a soft iron rod and bend it into a circle about three or four inches in diameter. (A core of soft iron wires may be used equally well.) Wrap two coils of about fifty turns each of wire around the core (Figure 428). Connect one coil in series with a switch and two or three dry cells. Connect the other coil to a galvanometer. Now close the switch. What happens? Now open the switch. What happens? What change takes place in the direction of the current as the switch is opened and closed?

Your experiment showed you that a current is produced in the coil connected with the galvanometer when the circuit is made. When the circuit is broken, a current is also produced, but this time in the opposite direction.

Now let us think of the kind of current produced by an alternating-current generator. You remember that the current first flows in one direction; then it dies down to zero and flows in the opposite direction. When an alternating current is sent through one coil of a transformer, the lines of magnetic force first cut the second coil in one direction; then, as the current reverses, they cut the coil

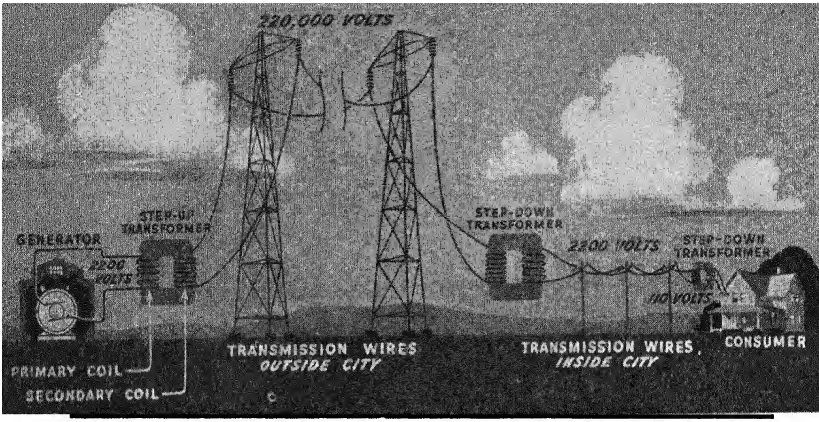


Fig. 429. This diagram will help you understand how a step-up transformer increases voltage for transmission and how a step-down transformer reduces the voltage for everyday uses.

in the other direction. In other words, the changing magnetic field has the same effect as if the second coil were being moved. The result is that an alternating current is produced in the coil.

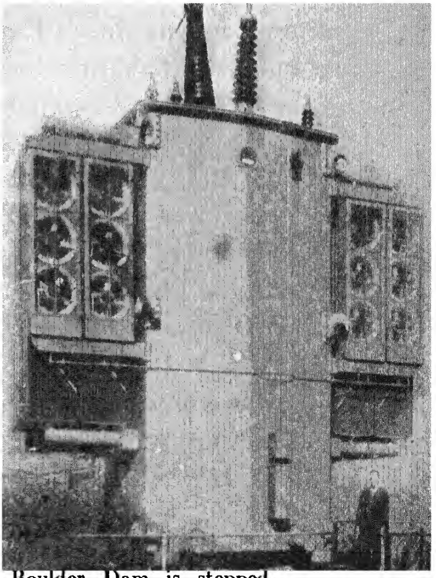
Now that you see how a transformer works, you can understand how it can be used to change the voltage of the current. Suppose that we want to increase the voltage. The generator producing an alternating current is connected with one of the coils around the armature. This coil is called the *primary coil*. We will suppose that there are 100 turns of wire in the primary coil. The *secondary coil* that is connected with the transmission lines has many more turns, say 2000 turns. The lines of force from the primary coil thus cut through 20 times as many turns in the secondary coil. The result is that the voltage in the wires attached to the secondary coil is 20 times as high as that in the primary coil. It has been increased, or "stepped up." If there were 110 volts in the primary coil, the voltage of the secondary coil would be 2200.

You must not forget, however, that the total amount of power in the secondary coil (less about 3 per cent loss) is the same as in the primary. If the primary coil carried

100 amperes at 110 volts, the secondary would have a voltage of 2200, but the current strength would be only five amperes. You can see why this must be true by the following figures:

Power in primary coil 110 V×100 A = 11,000 watts.
Power in secondary coil 2200 V×5 A = 11,000 watts.

By using step-up transformers, the electrical engineers can raise the voltage and lower the amperage. This greatly reduces the loss of energy. However, very high voltages cannot be used because energy is lost in other ways. Most city power stations use generators that produce current at 2200 volts. Such a large voltage cannot be used safely in the home; so it must be reduced. This is done by a *step-down* transformer. In a transformer of this kind the number of turns of wire on the primary is 20 times as great as on the secondary. In such a transformer the voltage would be stepped down to 110 volts in the secondary coil. At the same time the number of amperes would be 20 times as great as in the primary coil. The small transformers used to operate electric trains and bells are also step-down transformers. They reduce the pressure of the 110-volt house-lighting current to 5, 10, or 15 volts.



Boulder Dam is stepped down from 287,000 volts to 132,000 volts by this transformer at Los Angeles. (Westinghouse photo)

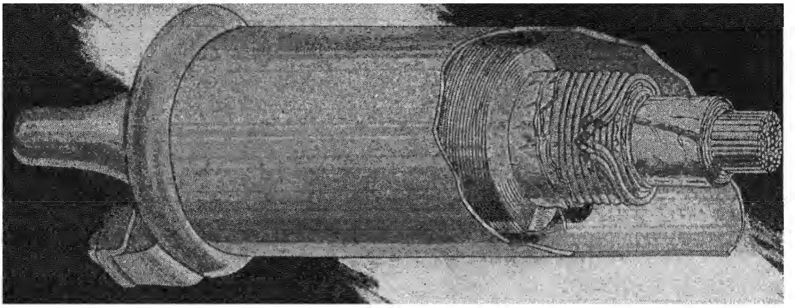


FIG. 431. A cut-away view of the kind of induction coil used in low-priced automobiles. You can plainly see the primary and the secondary coils.

The spark plugs in your automobile are connected to a special kind of transformer called an *induction coil.* In an induction coil the primary coil is placed inside the secondary coil. Since the battery of the car furnishes direct current, it is necessary to make and break the current, as you did in Experiment 45, in order to change the magnetic field and thus produce a current in the secondary. To do this a circuit breaker is used. This is connected to the engine, and it makes and breaks the circuit each time a spark is needed.

To force the spark across the gap in the spark plug, a pressure of 3500 to 15,000 volts is needed. In order to get this pressure, the primary is wound with 150 to 250 turns of comparatively large copper wire, which is connected with the six-volt storage battery. The secondary coil is wound with about 20,000 turns of fine copper wire. The total length of the wire on these two coils amounts to over a mile.

Self-Testing Exercises

1. Why must the electrical pressure (voltage) of a current be increased when it is transmitted a long distance?

2. How does a step-up transformer operate to increase electrical pressure?

3. How does a step-down transformer operate?

4. How does a transformer operated by direct current differ from one operated by alternating current?

FIG. 432. Samuel F. B. Morse

FIG. 433. Alexander Graham Bell

Problems to Solve

1. Find out exactly how an induction coil works.
2. Find out how induction coils or transformers are used to operate neon lamps.
3. What would happen to the motor on a toy electric train if a step-down transformer were not used? Why?
4. Find out how an induction coil is used to provide a spark in a gasoline engine.

Problem 6:
HOW IS AN ELECTRICAL CURRENT USED FOR SENDING MESSAGES?

ON MAY 24, 1844, an event occurred that has played a great part in the development of our modern world. It was on this date that the first message from one city to another was sent by electrical current. The words were "What hath God wrought," and they were sent by telegraph from Washington to Baltimore by the inventor, Samuel F. B. Morse. About thirty years later on March 10, 1876, another historic message was sent. Alexander Graham Bell said to his assistant, Thomas Watson, "Mr. Watson, please come here! I want you." As you probably

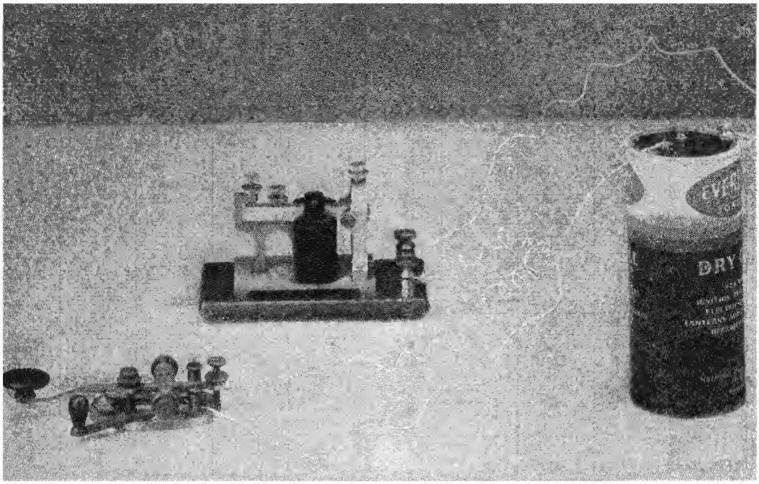


Fig. 434. Sending key, sounder, and battery of a simple telegraph set

know, this message was sent by telephone. Twenty years later, in 1896, Guglielmo Marconi sent a message two miles without the use of wires. This event marked the beginning of the use of the radio.

And now another new invention has been perfected after twenty years of experimentation. In 1927 scientists of the Bell Telephone Laboratories gave a public demonstration of television, in which pictures of a person before the transmitting instrument in Washington appeared at the same instant in the receiving instrument in New York City. Just as this book was being published, television on a large scale was being introduced. Thus in a little less than a hundred years our methods of communication have been completely revolutionized.

HOW ARE MESSAGES SENT BY TELEGRAPH? First, make a simple telegraph outfit to see how it operates. Then you can more easily understand how it works.

EXPERIMENT 46. *How Is a Simple Telegraph Instrument Set Up and Operated?* (*a*) Connect a cell, a *sending key*, and a *sounder* as in Figure 434, using two wires to complete the circuit. Open the switch on the key. Press down on the key. What happens? Release the key. What happens?

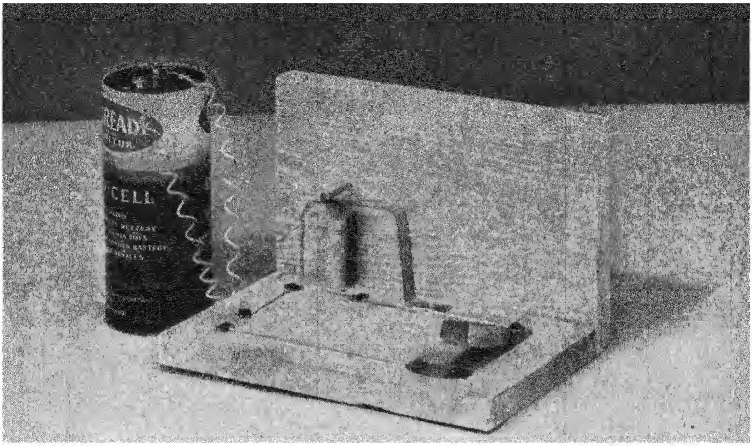


FIG. 435. A home-made telegraph. At the right is the key. The sounder clicks between the nail and the top of the electromagnet, which is a nail wound with wire.

b) Press down on the key and release it immediately. You hear two clicks close together. This is called a *dot*. Press down on the key, hold it an instant, and then release it. You now hear two clicks not so close together as when you made a dot. This is called a *dash*. The difference between a dot and a dash is the difference in time between the two clicks, and these dots and dashes make up the telegraphic code. Try sending a series of dots and dashes until you can tell them apart.

c) If you do not have a commercial key and sounder, make an instrument as shown in Figure 435. Use about fifty turns of wire on the nail.

Perhaps by now you already understand how the telegraph works. If you do not, this is the explanation: The two round spool-like parts in the sounder contain a horseshoe-shaped electromagnet. The little bar (armature) that goes across the poles of this electromagnet is made of soft iron. This cross-bar is attached to a heavier steel bar that can move up and down. A spring holds the steel bar, so that the end stays up against a small screw in the frame. Now you can understand what happens in the electric circuit when the key is pressed and released.

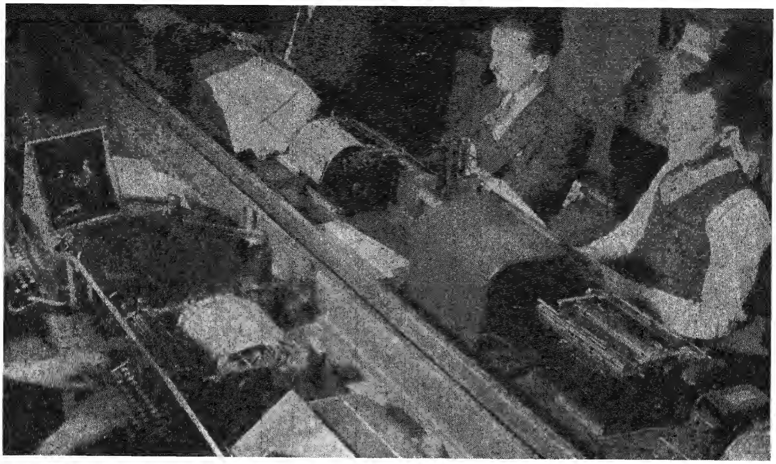


FIG. 436. These telegraph instruments in the office of a great newspaper type their messages directly on to a ribbon of paper. The ribbons pass across typewriters, where men copy the messages on sheets of paper. (New York Times Studio)

When the key is pressed down, the circuit is completed. The electrical current flows from the cell around through the coils of the magnet through the key and back to the cell. When this happens, the electromagnets pull down the armature, and a click is heard. When the key is released, the circuit is broken. Then the electromagnets lose their magnetism, the spring pulls the armature up, and another click is heard as it strikes the upper screw. When the key is pressed down again, the same events take place all over again. A telegraph circuit thus contains a source of electricity, a device to make and break the circuit (the key), and a device that uses an electric current to make sounds (the sounder).

Simple instruments of this kind are still widely used in railroad communication and for lines where few messages are sent. In many cases only one wire is used with these instruments; the ground takes the place of the other wire in the circuit. For commercial telegraphy, where thousands of messages may be sent over a line in a day, many complicated devices have been invented to speed

up the sending and receiving of messages. For example, messages may be sent by striking keys like those on a typewriter. At one or many receiving stations, machines called *teletypewriters* receive the electrical impulses from the receiving instrument and automatically type out the letters of the message on a sheet of paper or on a paper tape. A single circuit can be arranged to carry messages from four or more sending instruments at the same time. All these and other inventions allow the telegraph lines to send messages quickly and cheaply.

Self-Testing Exercises

1. Explain how a telegraph sounder produces sounds.
2. Why is a key necessary in a simple telegraph circuit?
3. What is a teletypewriter?

HOW DOES A TELEPHONE WORK? When you talk over the telephone to a person a few miles or even thousands of miles away, you can hear the person as well as if he were standing near you. He speaks in his usual way, and so do you. Neither of you shouts, but still you can hear one another. Ordinary sound waves, as you know, could not travel this distance and be heard. Furthermore, you hear the person as he speaks. It would take several seconds for the voice of a person ten miles away to reach you through a wire. You see, therefore, that it is not sound, as many people think, that is sent through the telephone wire.

We will suppose now that you are talking over a telephone. What happens? Sound waves are set up in the air as you speak. These sound waves enter the mouthpiece of the *transmitter* (Figure 437). Inside the transmitter is a thin piece of metal, the *diaphragm*. When the sound waves strike the diaphragm, they make it vibrate back-

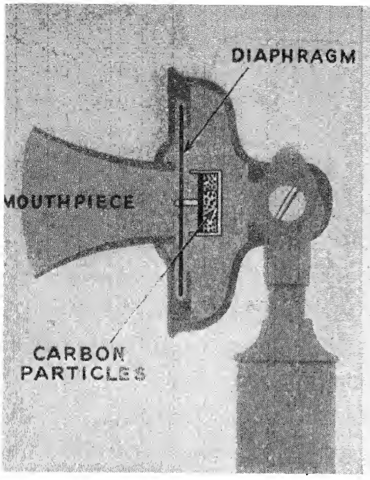


FIG. 437. The transmitter of a telephone

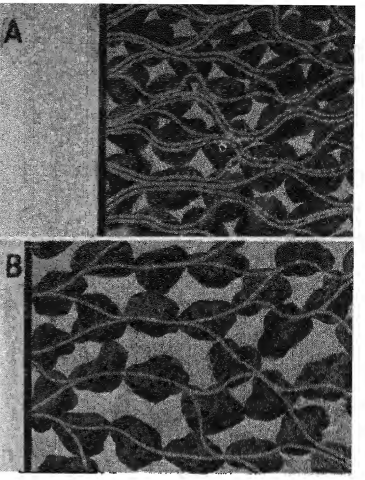


FIG. 438. Carbon particles in a transmitter

ward and forward. For example, if the sound wave vibrates 256 times per second, the transmitter diaphragm will vibrate at the same rate. Attached to the back of the diaphragm is a little box containing carbon particles through which the current must pass. As the diaphragm moves in, these carbon particles are pressed closer together (A of Figure 438), and their resistance to the passage of an electrical current is decreased.

Some source of electrical current, such as a dry cell, is connected in series with the box of carbon particles. As you already know, when the resistance is decreased, more current can flow. So every time the diaphragm goes in, the strength of the current is increased. When the diaphragm moves back out again, the resistance is increased; therefore less current flows through the carbon. The strength of the current therefore increases, then decreases, then increases, and so forth. For this reason the electric current that flows through the transmitter and out into the wire going to the *receiver* changes from a strong current to a weak current, then back to a strong current, and so on. It makes these changes the same number of

times per second that the sound wave strikes the transmitter. Such a current may be called a *pulsating current*, or a *fluctuating current*.

At the receiver end of the circuit it is necessary to change this pulsating current of electricity back to sound waves so that you can hear. This is done in the receiver of the telephone. If you unscrew the cover of a telephone receiver, you will first see a metal diaphragm (Figure 439). When the diaphragm is removed, you see two electromagnets wound with many turns of wire. These electromagnets receive the pulsating current from the transmitter. What happens then?

When the current gets stronger, the electromagnets become stronger, and they pull the center of the diaphragm inward. When the current gets weaker, the pull on the diaphragm is released, and it flies back to its original position. The diaphragm, therefore, moves inward and outward at the same rate at which the current changes its strength. As it does this, it sets up sound waves in the air. These sound waves travel to your ear, and you hear. The diaphragm in the receiver vibrates at the same rate as the sound wave that struck the diaphragm in the transmitter. Therefore you hear the voice that set up the sound wave.

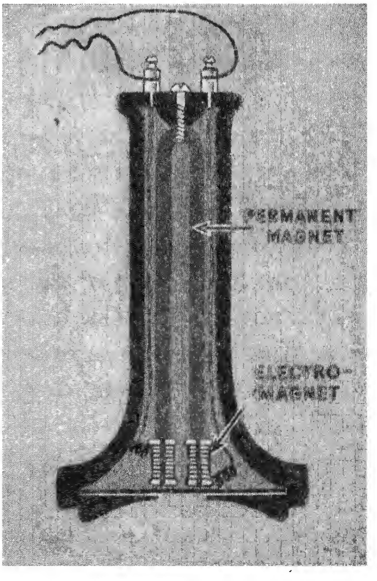


FIG. 439. A telephone receiver

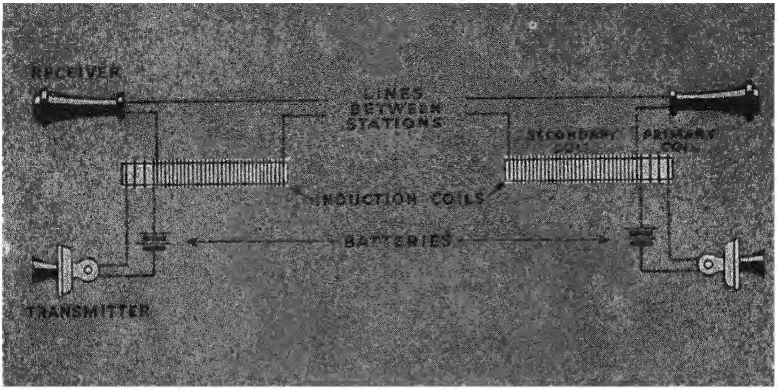


FIG. 440. The induction coils in a telephone circuit

In actual practice telephone circuits also use induction coils. You remember that an induction coil is a type of transformer used to change the voltage of a current. When stations are some distance apart, it is necessary to step up the voltage. To do this, an induction coil is connected in the circuit (Figure 440). The pulsating current in the transmitter circuit is connected with the primary of an induction coil. It sets up a high-voltage alternating current in the secondary coil. This secondary coil is connected to the wires that connect with the receivers of other stations. The alternating current in the secondary coil has the same effect on the electromagnets of the receiver as the pulsating direct current. That is, it increases and decreases in strength and thus increases and decreases the pull of the electromagnets in the receiver.

Of course, few telephones are as simple as the one you have just been reading about. Near each instrument there is usually a bell and devices for ringing the bell to call someone to talk on the phone. If there are many phones in the system, an *exchange* is necessary. In the exchange a person called an *operator* answers your call, calls the person you want, and connects your phone with the other phone. Many other devices in the exchange turn signal lights on and off, give "busy" signals, and help in other

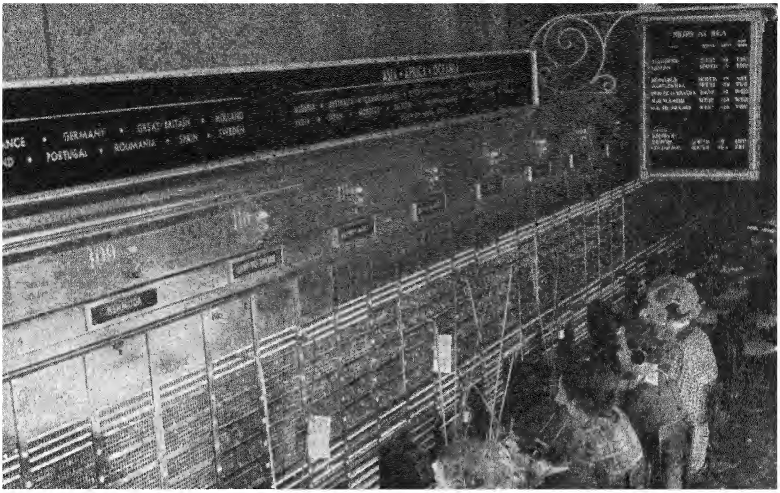


Fig. 441. Through this overseas radio telephone switchboard in New York City, one can communicate with foreign countries and with ships at sea. (Photo by R. I. Nesmith and Associates)

ways to give good telephone service. In some exchanges the connections between telephone instruments are made by machines instead of by human operators. These machines are much too complicated to explain here.

Self-Testing Exercises

1. What passes along a telephone wire to carry the message from you to a friend?
2. Explain carefully what happens in the telephone transmitter while you are talking.
3. Explain carefully what happens in the telephone receiver at your friend's ear while you are talking.
4. Draw a diagram of the simplest telephone circuit you can imagine.

Problems to Solve

1. Try to make a telegraph circuit that will work by using the ground in place of one wire. Push a spike nail or iron rod into moist soil at each instrument. Connect one wire from each instrument to the spike or rod and have the second wire run all the way between the instruments.

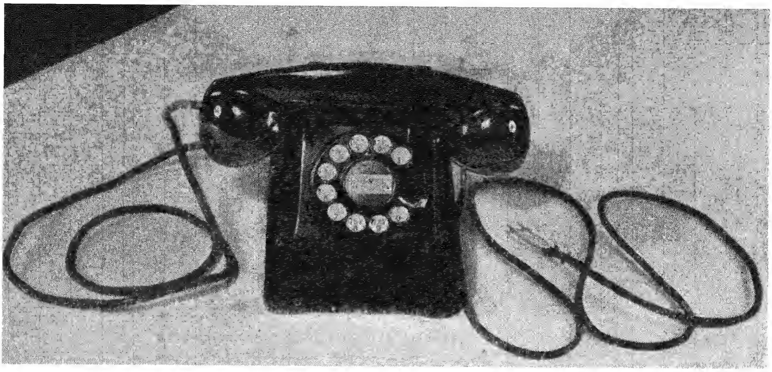


FIG. 442. The new-type hand telephone with a dial for calling numbers. Receiver and transmitter are all in one piece.

2. Plan a telegraph circuit that will include two sounders and two keys so that messages can be sent in either direction.

3. Read in reference books about Samuel F. B. Morse and his invention of the telegraph.

4. (*a*) What can you find in reference books about telegraph systems?

b) Find out what a telegraph relay is and how it works.

5. Learn the telegraph code of dots and dashes well enough to spell out your name.

6. Obtain a telephone transmitter, receiver, and dry cell. Connect them so that the sound of tapping on the transmitter can be heard in the receiver. Demonstrate the circuit and operation to the class.

7. Visit the nearest telephone exchange and ask to be shown as much as possible of its operation.

8. Read in reference books about Alexander Graham Bell and his invention of the telephone.

9. Learn all you can about automatic telephone exchanges and how they work.

HOW DOES A RADIO WORK? In the telephone you have seen how sound waves can be used to change the strength of an electric current, how the pulsating electric current is used to change the strength of an electromagnet in a telephone receiver, and finally how this magnet operates the diaphragm to produce sound waves again.

This is practically the same process that must take place in transmission by radio. The big problem in radio is to transmit electrical energy without the use of wires.

Let us first see how electrical energy travels through air or empty space without the use of wires. You already know that sound and light are transmitted by waves. It should be no surprise to you to learn that there are also electromagnetic waves. These waves, like light, can travel through a vacuum at the speed of 186,000 miles a second.

In the broadcasting station is an apparatus that generates a very rapidly alternating current. This generator causes electrons to flow back and forth in the *aerial* (wires or tower) that sends out the radio messages. For example, if a station is operating on a *frequency* of 600 *kilocycles*, the current is rushing up and then down the aerial 600,000 times per second. As the current rushes up and down the aerial, it sets up electromagnetic waves that travel out from the aerial. Six hundred thousand waves per second are sent out at the rate of 186,000 miles per second. Each station must have a very complicated set of radio tubes, coils, and other devices to send out waves at just the correct frequency for that station.

To listen to a certain station, you know that it is necessary to tune your set to the frequency upon which the station is operating. Now let us see why this is necessary. When you studied sound, you learned about sympathetic vibrations (pages 356-358). You found out that a sound wave of a certain frequency could make another body vibrate and produce sound if the frequency of the sound wave was the same as the frequency at which the body would vibrate. By tightening or loosening a violin string, a musician can tune the string until it will vibrate in sympathy with a string on a second violin. A somewhat

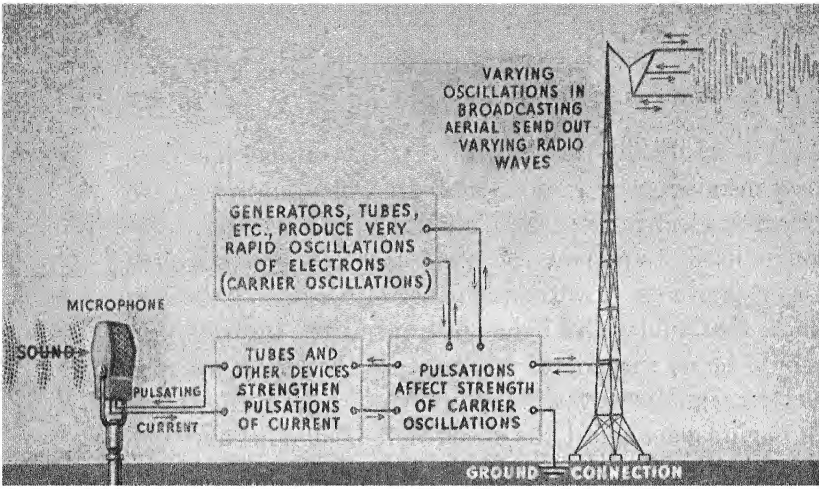


FIG. 443. A simple diagram of a radio sending station

similar thing happens in radio. The electrons in the aerial of a radio set will respond to a certain frequency of electromagnetic waves. By the use of coils and other devices in the set, it is possible to change the frequency to which the aerial and the receiving instrument will respond. In other words, tuning a set means changing it so that it will respond sympathetically to the frequency of the station you want.

Now let us come back to the broadcasting station. The singer or speaker sings or talks into a microphone. This microphone is really nothing but a very sensitive transmitter, such as is used in the telephone. The sound waves striking the microphone cause a pulsating electrical current in the wires connected to it just as they do in the telephone transmitter. By very complicated arrangements in the sending station, the pulsating microphone current changes the strength of the radio waves that are being sent out from the aerial. These changes correspond to the sound waves that strike the microphone. Figure 443 shows you what happens to sounds after they enter a microphone.

Now we have the electromagnetic waves, or *radio waves*

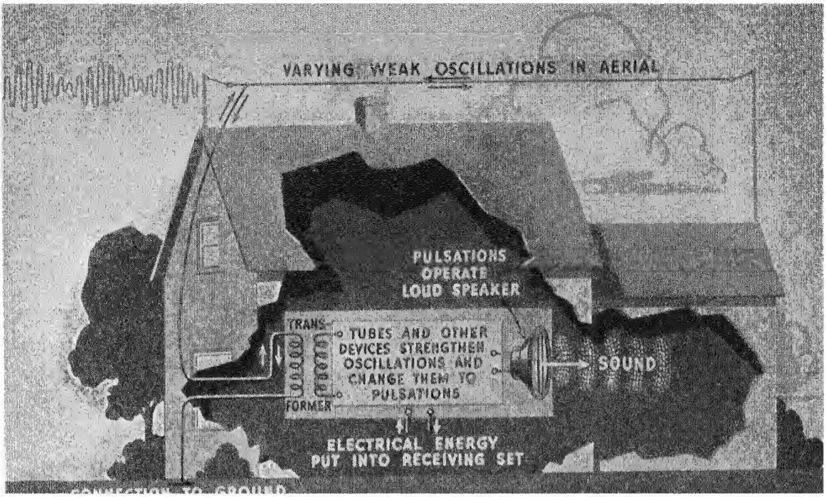


FIG. 444. A simple diagram of a radio receiving station

as they are called, going out into space. These radio waves strike the aerial of your receiving set that is tuned to respond to those particular waves. The electrons in the aerial and the set begin to rush up and down your aerial at the same frequency as they are rushing up and down the aerial of the sending station. Of course, this alternating current in your set is much weaker than in the sending station. To strengthen it your receiver must be connected to a source of electrical energy (Figure 444).

First, the feeble but very high-frequency alternating current is *amplified*, or strengthened, by the "radio" tubes in your set. Of course, the electrical energy supplied to the set helps do this. Next, the alternating current is sent to a special tube called a *detector*. In this tube the high-frequency alternating current is changed to a pulsating direct current. This direct current pulsates in the same way as the current in the microphone. This current is again amplified by being sent through transformers and tubes until it is powerful enough to operate the electromagnet in the loudspeaker. Then the diaphragm in the loudspeaker sends out sound waves that you hear.

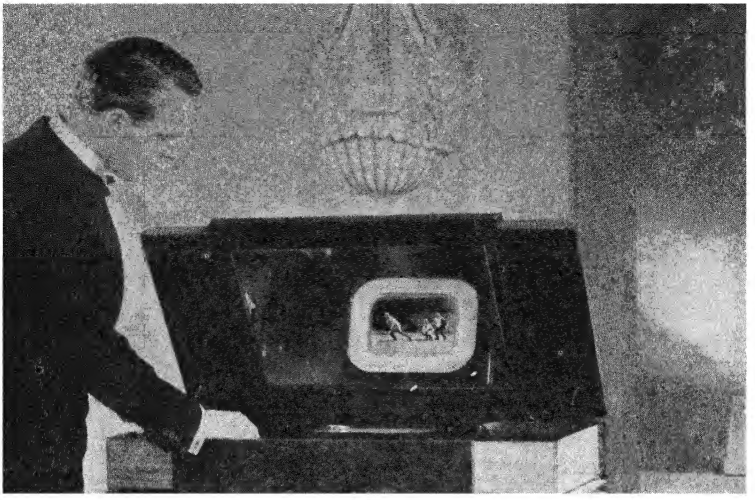


FIG. 445. A television receiver. The picture produced by the receiver is reflected from a mirror in the cover. (R. C. A. Laboratory photo)

HOW DOES TELEVISION WORK? Unless you live in a part of the country where there are television stations, you have probably never seen a television set work. In a television set a picture of what is happening in the broadcasting station is sent to you by radio. You see the singer as you listen to him. In this respect, it is like the talking pictures in the movies.

Television differs from ordinary radio in two important ways: First, light waves (instead of sound waves) must be used to change the strength of the current sent out by the aerial. Second, the electromagnetic waves that can be used in television are very much shorter waves than those in the radio. They travel in straight lines, and the distance at which they can be used to operate receiving sets is very limited. So far, only a few large cities have television broadcasts, and these can be received for only a few miles from the station.

In this elementary textbook you can get only a few general ideas of how television operates. At the sending-station the scene to be sent (*televised*) is illuminated with

a strong light. The objects in the scene reflect light to a camera-like piece of apparatus. The dark parts of the objects reflect less light than the light parts. The amount of light reflected from various parts of the object sets up a pulsating current in the camera-like apparatus. This pulsating current controls the strength of the high-frequency waves sent out by the aerial of the sending station. At the receiving end the pulsating current that is produced operates a special kind of tube which forms a luminous picture of the object televised.

Self-Testing Exercises

1. How are radio waves produced?
2. What is meant by "tuning" a receiving set? Why must it be in tune with the sending station?
3. What effect do the electrical pulsations in a radio microphone circuit have on the waves that leave the sending aerial?
4. Why does a receiving radio set need to be connected to a source of electric current?
5. State one use of radio tubes.
6. What is television?

Problems to Solve

1. How many differences can you find between radio waves and sound waves?
2. How does a vacuum tube of a radio work? Find what you can about these tubes in reference books.
3. How are electrical *condensers* used in radio sets?
4. Examine the working parts of a radio set and learn what changes are made while the set is being tuned.

LOOKING BACK AT UNIT 8

1. All the useful things that electricity does are possible because of four or five effects that an electric current has. For example, an electric current can produce heat.

a) Complete the list of useful effects of electric currents.

b) Under each effect, list the devices you have studied or know about that make use of that effect. For example, under the heating effect you would list electric irons and toasters.
c) Under each effect explain what transformation of energy has taken place.

2. Show that you know the meaning of the following terms:

resistance (*electrical*)	*arc* (*electrical*)	*commutator*
incandescent bulb	*volt*	*brushes*
filament	*watt-hour meter*	*electrolysis*
frequency (of radio waves)	*magnetic field*	*transformer*
radio wave	*ion*	*secondary coil*

ADDITIONAL EXERCISES

1. Suppose that an electric bell rang very feebly. What might be the matter with it?

2. Read about the scientific discoveries of Michael Faraday.

3. Find out why a special circuit is usually put in a house when an electric range is installed.

4. Find out the rate per kilowatt-hour in your city. Then figure out how much it costs to light your living-room for three hours.

5. Why will you get a shock if you touch the spark plugs while an automobile engine is going?

6. Find out how the electrical system of an automobile is constructed so that it generates its own power, lights the lamps, turns over the starter, and supplies a spark to the spark plugs.

7. Visit a telephone exchange and find out how two subscribers are connected with each other.

8. Find out how automobile horns are operated.

9. If there are any high-voltage lines near your city, find out the voltage at which the current was generated and the voltage sent through the line.

10. Find out why direct-current generators are used on automobiles rather than alternating-current generators.

11. In reference books read about the discoveries of André Ampère and Alessandro Volta.

FIG. 446. The world's largest windmill harnesses the energy of the wind to produce 1000 kilowatts of electrical power. Built on a windy hill near Rutland, Vermont, its steel tower stands 120 feet high. The blades, which measure 175 feet from tip to tip, travel at speeds up to 200 miles an hour in a strong wind. The energy of the wind is only one kind of energy that people have harnessed to do their work. In this unit you will find out some of the important things that scientists have discovered about energy and the ways of harnessing it. (Kurt Schelling Fortune photo by special permission)

UNIT NINE

UNIT 9

HOW DO WE HARNESS THE ENERGY OF NATURE TO DO OUR WORK?

INTRODUCTORY EXERCISES

*1. Name the form of energy in each of the following: (*a*) a speeding automobile, (*b*) a piece of coal, (*c*) the water of a mountain lake, (*d*) the wind, (*e*) sunlight, (*f*) a gallon of gasoline, (*g*) a lifted weight, (*h*) a piece of bread.

*2. (*a*) How does the sun make the wind blow? (*b*) How does the energy of the sun get into a piece of coal?

*3. What important change of energy takes place while a piece of coal is burning?

*4. Tell briefly the story of a drop of water as it travels from an ocean to a mountain stream. In which place does it have the more energy?

5. Draw a simple diagram to show how water from a lake behind a dam reaches a water-wheel and turns it.

6. How is steam produced to run a steam engine.

7. (*a*) Tell all you can about how a locomotive works. (*b*) Where does the locomotive get energy to pull a train?

8. What is a steam turbine? How is it different from a steam engine?

9. Why does a gasoline engine need a carburetor? Spark plugs? Pistons?

10. How is a Diesel engine different from the gasoline engine in an automobile?

11. Fill in a table like the one below to show the uses of the different kinds of power machines.

Wind-Power	Water-Wheels	Steam Engines and Turbines	Gasoline and Diesel Engines
Pumping water, etc.	Etc.		

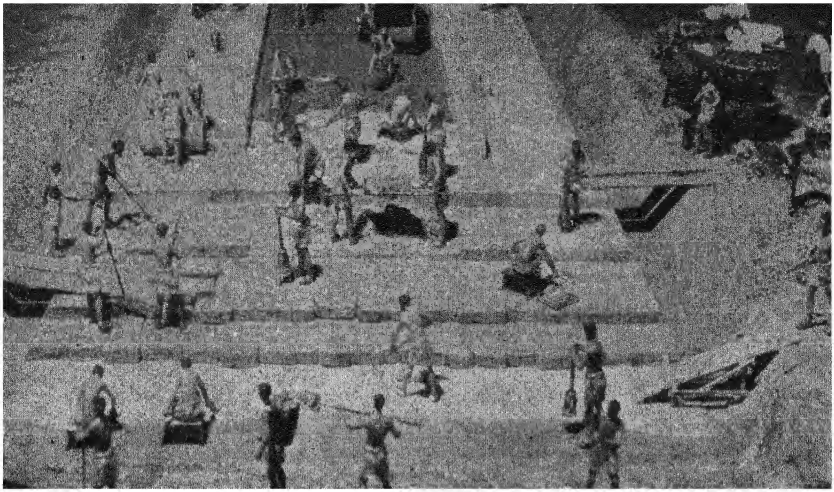


Fig. 447. How the Romans built their roads. You can see many simple machines—inclined planes, levers, and wheels. But the only power machines are the men and the animals that pull the carts. (U. S. Bureau of Public Roads photo)

LOOKING AHEAD TO UNIT 9

You have already learned what we mean in science when we talk about doing work. Work is overcoming some resistance, moving something that resists being moved. In this world there is a great deal of work to be done. Materials of various kinds have to be lifted, sawed, cut, ground, and mixed. Soil has to be cultivated. Tunnels, ditches, and canals have to be dug. Water must be pumped, and fibers spun into thread, woven into cloth, and sewn into clothing. Men and goods must be carried about over the earth. Books, magazines, and newspapers must be printed. Radios, telephones, and telegraphs must be operated. As you know, energy is needed whenever any of these kinds of work is to be done. Let us see how man's ways of obtaining energy to do this work have changed through the ages.

When all men were savages, their work was done with their muscles; that is, they got energy in the food they ate and then oxidized the food in their muscles. This

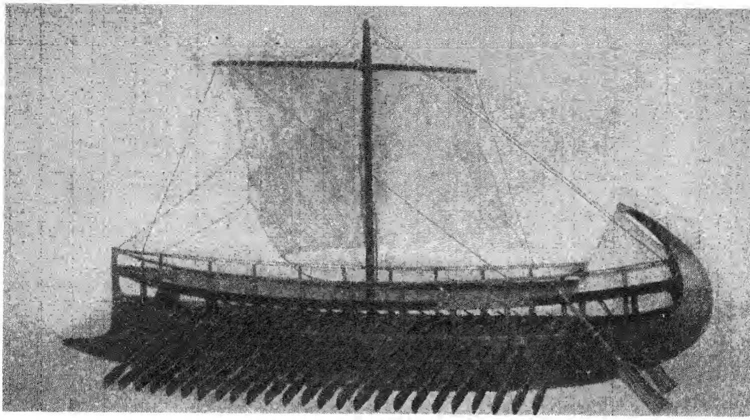


FIG. 448. Fifty men pulled at fifty oars to move boats like this one through the water about 3000 years ago. Sometimes the sail harnessed the energy of moving air to add to the energy of the men. (Philadelphia Commercial Museum photo)

turned loose the stored energy of the food and made the muscles move. With their muscles men walked and ran, carried their burdens, built their crude shelters, made their clothing, and cultivated their crops. Later, men learned to tame animals and to make harness for them. Thus men could get much more work done with less effort on their own part. Yet the work was still done by muscles with the energy of food. As the centuries rolled on, the minds of inventive men saw that there was energy in wind and in the water of the rivers running down to the sea. So they hoisted sails of skins and crude cloth to harness the wind to their boats. They constructed windmills and water-wheels to run their mills. In all these ways they were discovering how to get more work done with less effort on their own part.

But some men seem never to be satisfied. They are always thinking up better ways of doing things. As far back as the time of the ancient Greeks, a few men had noticed that steam, produced with the heat of a fire, would exert great pressure and blow containers to pieces

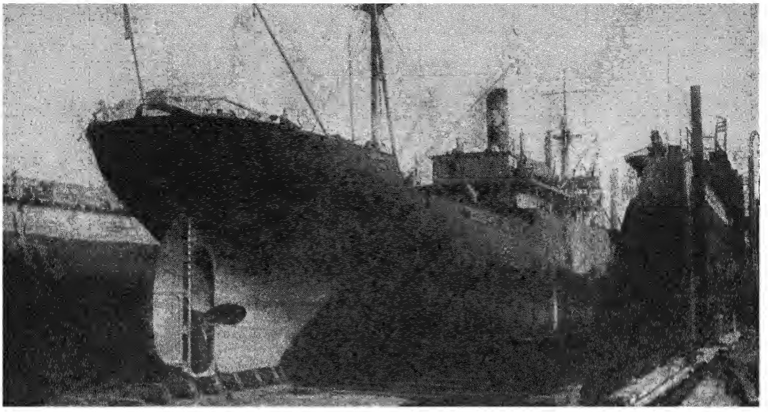


Fig. 449. This ship is probably two or three times as large as the one shown in Figure 448. But one screw propeller turned by power machines moves the heavy ship more steadily and more swiftly than 200 men with oars could move it.

if it were not allowed to escape. As a result of these observations, Hero of Alexandria made a kind of steam engine that would actually run. However, it was nothing more than a toy. It would not do much work.

Not until about the year 1700 was the energy of steam successfully put into harness. About that time the miners of England were having great difficulty pumping water out of the mines. At some mines as many as 500 horses were used on treadmills to run the pumps. This was very awkward and expensive. To run the pumps various kinds of crude steam engines were made, until finally, about 1769, James Watt invented a quite efficient engine; it was much like the steam engines still in use. Soon steam had been harnessed to all kinds of jobs! It pulled trains, propelled boats, pumped water, ground grain, sawed wood, spun thread, and wove cloth. Still later, a wonderful kind of steam windmill, called the *steam turbine*, was invented and put to work driving ships, pumping water, and generating electric current. The steam engine and the steam turbine can use the energy of fuels such as wood, coal, and oil to do work.

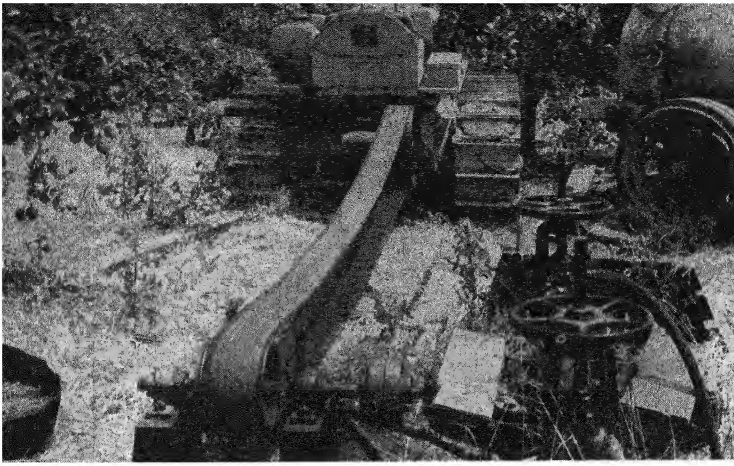


FIG. 450. In this tractor is a Diesel engine that harnesses the energy of oil both to move the tractor and to run other machines. Here the engine is furnishing power to run a water pump to irrigate 1000 acres of walnuts, lemons, peas, and avocados on a ranch in California. (Caterpillar Tractor photo)

Most steam power-plants are heavy and awkward. They can best be used in buildings, large boats, or locomotives. So inventors kept trying to make a light kind of power machine to drive small vehicles and flying machines. Finally, about sixty years ago the gasoline engine was invented. As soon as it became dependable, it was used wherever a light and efficient engine was needed. It has been developed and improved until today we have powerful and economical gasoline engines.

How are these power machines important to you? What difference do they make in your life? The answers to these questions depend on who you are and where you live. On the average, machines are doing as much work for each person in our country as ten people could do working constantly. This means that, on the average, each of us can have better food brought greater distances, more and better clothing, better homes, more music, books, education, and leisure, and can travel farther and more easily than our great-grandfathers could.

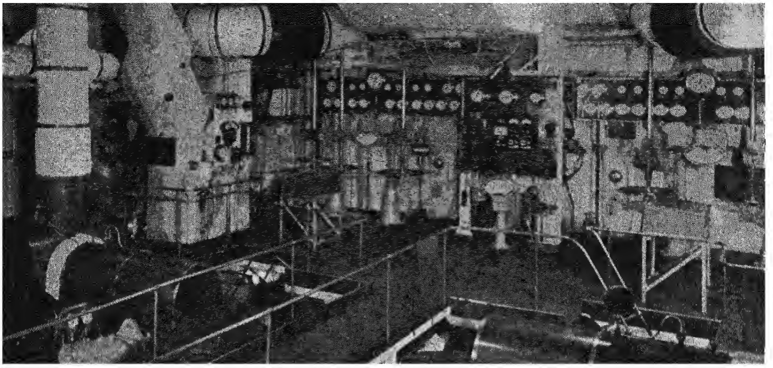


FIG. 451. This picture shows the starting platform in the engine room of a great ocean liner. It takes all these devices, and more, just to regulate the power machines that are needed to run a modern steamship. (Cunard White Star photo)

From these facts you can see that the machines which harness the energy of nature are very important to you and to your country. You will want to know many things about them. How do windmills work? How can water-power plants make electrical current? How do steam engines work? What is a steam turbine? How does gasoline make an automobile go? How are Diesel engines different from other engines? What is horse-power? Where does all this energy come from? What will happen when all our coal and oil are gone? In this unit you will find the answers to most of these questions.

Problem 1:
HOW IS THE ENERGY OF WIND AND WATER PUT TO WORK?

YOU HAVE often seen the wind doing work. The slightest breeze rustles the leaves of trees and moves their branches back and forth. A strong wind pushes you as you walk along, and sends hats whirling. Tornadoes tear houses apart and lift the pieces and carry them far away. Moving water does work, too. You have read in *Science Problems, Book 2,* how it carves great river valleys out of solid rock. Water can exert a greater force than wind and can move heavier objects because it is much more

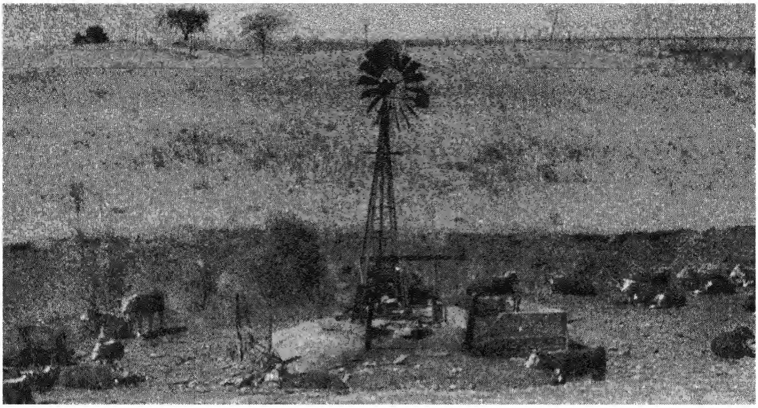


FIG. 452. If you have traveled through farming districts, you have seen many windmills at work. Wheels like this one harness the wind to pumps that lift water to the surface of the ground for the farmer's horses, hogs, and cattle.

dense than air. But both wind and running water have a great deal of energy of motion, or *kinetic energy*. As you already know, man noticed this energy and began to put it to work for him a long time ago. It is doing much of the work of the modern world. Let us see how machines are arranged to harness this energy.

HOW IS WIND HARNESSED? The first harness made for the wind was probably on some small prehistoric boat. It was, in some ways, much like the harness made for a horse. Men in the boat fastened a small sail to sticks of wood and held it up for the wind to push against, just as a horse pushes against the collar of its harness. Through the centuries men learned how to make better and bigger sails, and they fashioned ropes, masts, and spars to hold the sails and to move them so that they could use a greater amount of the wind's energy.

Thus, during all the centuries before steamboats were invented, man relieved himself of the work of propelling his ships by harnessing the wind and using its energy. But today, sails are seldom used except for pleasure boats and the boats of savages who have not learned to

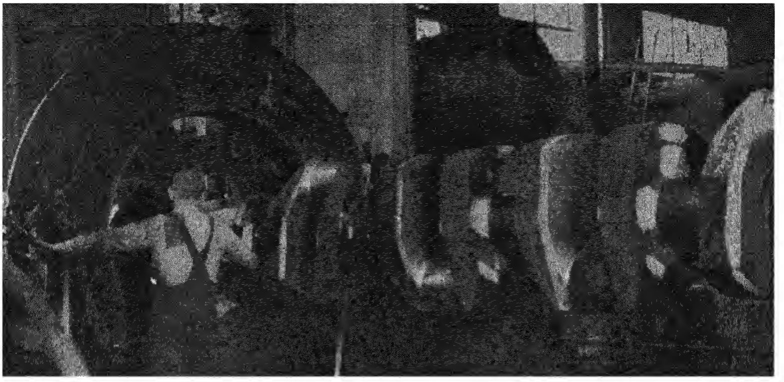


Fig. 453. The crank shaft of an automobile engine is used to change the up-and-down motion of the piston into circular motion. This machinist is making a giant crank shaft to be used in an eight-cylinder, 1000-horse-power Diesel engine for the light and power plant at Forest City, Arkansas. (Nesmith and Assoc. photo)

use steam or gasoline engines. However, many windmills are still in use for doing work.

Before you begin to find how these windmills work, think about what we mean by "harnessed" energy. You have already learned that there are several different forms of energy, such as kinetic energy, potential energy, radiant energy, heat, and electric energy, and that one kind of energy can be easily changed into another form of energy. To do work we usually need the energy of motion, or kinetic energy, instead of potential energy.

Two forms of motion are most often needed by the machines that do our work. One of these is back-and-forth motion, such as we find in a tire pump or a water pump. This is known to engineers as *reciprocating motion.* The other kind of motion is the round-and-round motion that is used with wheels. This circular motion is often called *rotary motion.* In the modern machines for harnessing energy you will notice either reciprocating motion or rotary motion or both. What each power machine does is to change the kind of energy it receives into reciprocating motion or rotary motion. Then it can conveniently

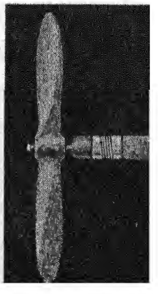
FIG. 454. A wind-operated generator

be used to do work for us, and we can say that the energy has been harnessed.

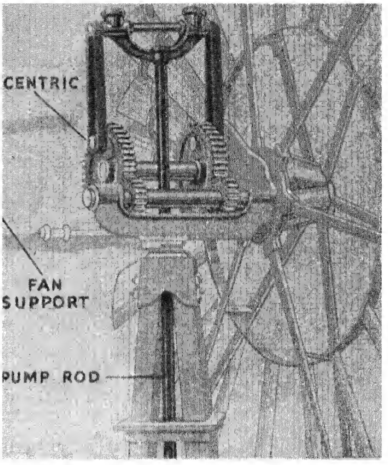
The energy of wind is already kinetic energy, because wind is air that is moving. All that we need to do to harness wind to a machine is to get the moving air to make something go round and round or back and forth. You have probably played with a toy windmill and watched it spin in the wind. If not, you can easily make one.

EXPERIMENT 47. *How Does a Toy Windmill Work?* Whittle a propeller from soft pine or balsam wood. Be sure that the blades are sloped as shown in Figure 455. Bore a small hole through the center and fasten the propeller on the eraser of a pencil with a pin. If you prefer, you may make a paper "pin-wheel." Blow on your windmill or hold it in a breeze. Does it turn? Why?

In the last few years many windmills like the one in Figure 454 have been put on the tops of farm buildings. These new windmills generate electric current for many purposes. The windmills attached to electric generators work just like your little wooden propeller. Notice Figure 454. The wind strikes the upper blade at an angle. Since the blade cannot move in the same direction as the wind, it tends to move to the right. The lower blade slopes the opposite way. Thus it tends to move to the left as the wind goes past it. With one blade



pushing to the right and the other to the left, the shaft of the windmill turns and drives an electric generator. In this way the constant forward motion of the wind is changed into the rotary motion needed for the generator. Small windmills of this type have been made so efficient that one foot of wind pushes the tip of a propeller through a distance of thirteen feet. These windmills are changing the energy of moving air into electric energy for thousands of homes and factories far distant from electric power lines.



The windmills that pump water work in just the same way as the two-bladed mill, but they have more blades to face the wind. Therefore they exert more force. To operate a pump, the rotary motion must be changed into reciprocating motion. To do this, two small gear wheels on the shaft of the propeller turn two large gears (Figure 456). A few inches from the center of each large gear wheel is a short pin extending out something like the handle of a crank. This is called an *eccentric* (meaning "off center").

Attached to the two eccentrics are two rods with a crosspiece at the top. As the eccentrics rotate, the crosspiece moves up and down and works the pump rod. Thus the rotary motion of the propeller is changed to the reciprocating motion of the pump rod. The propeller is fastened to a pivot and provided with a "tail," or fan, so that the propeller always faces the wind when running. The

propeller can be turned parallel to the tail. Then it no longer faces the wind and will not rotate.

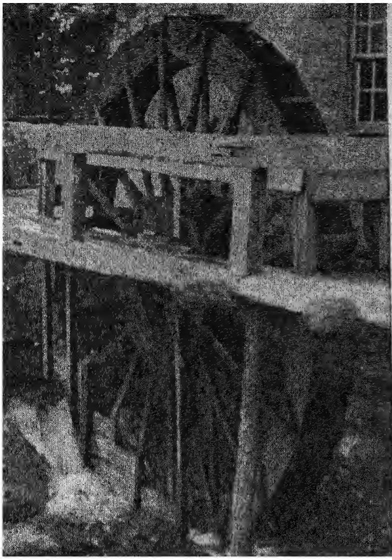
The energy of the wind is free, but it is very unreliable. Furthermore, very large windmills are exceedingly hard to build. Any wheel large enough to develop as much power as an automobile engine would be very expensive and would be likely to blow down in the first wind-storm. So long as there are other good sources of energy, wind power will be used only for small jobs in the country.

Self-Testing Exercises

1. Name three kinds of work done with the energy of wind.
2. What is rotary motion? Reciprocating motion?
3. Tell how a simple windmill changes the motion of the wind into rotary motion.
4. Give one reason why we do not use the wind to do much of our work.

HOW DO MODERN WATER-POWER PLANTS WORK? Only a few of the water-wheels of colonial days in our country are still in use. Many that are still running are of value chiefly as antiques. These wheels were of two main types, the *undershot wheel* and the *overshot wheel*. The undershot wheel was used where there was a great amount of water from a low dam. The kinetic energy of the water striking the blades at the bottom of the wheel was transferred to the wheel and changed to rotary motion.

The overshot wheel (Figure 458) worked best where a higher source of water was available. The water at the top of this wheel possessed potential energy. It was poured into the "buckets" of the wheel. As gravity pulled it downward, the potential energy of the water changed into kinetic energy and made the wheel rotate. You can see that both these kinds of water-wheels are simple wheel-and-axle machines. The force of the water acting



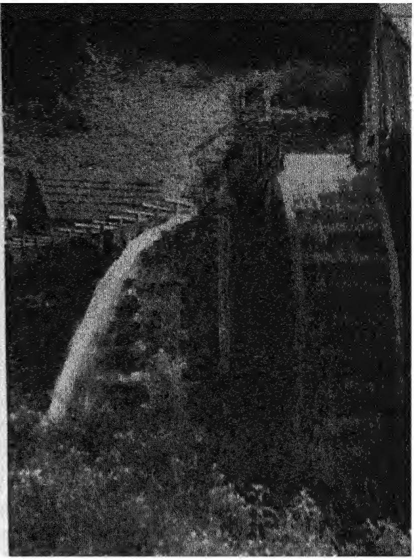


FIG. 457. An undershot waterwheel in New York State (H. W. Fechner photo from Nesmith Assoc.)

FIG. 458. An overshot waterwheel at Dillingham, No. Carolina (Nesmith and Associates)

on the rim of the wheel exerts a greater force and does work near the axle.

Scattered here and there along the streams of our country are many small water-power plants used for small mills and small electric generators. However, the most important plants are those at great dams or falls where large amounts of water are available. Table 3 gives a number of the large plants and the amount of

TABLE 3. SOME OF THE GREAT WATER-POWER PLANTS IN THE UNITED STATES

Place	Stream	Horse-Power Produced	Planned for Future Use
Niagara Falls, N. Y..	Niagara River....	950,000	950,000
Boulder Dam.........	Colorado River...	1,388,000	1,772,000
Conowingo, Md.......	Susquehanna.....	378,000	378,000
Keokuk, Iowa........	Mississippi River.	150,000	300,000
Bonneville, Ore.......	Columbia River..	695,000	695,000
Grand Coulee, Wash...	Columbia River..	1,096,000	2,646,000
Wilson Dam.........	Tennessee River..	260,000	610,000
Approximate Total in United States......	....	18,862,000	(Available) 43,000,000

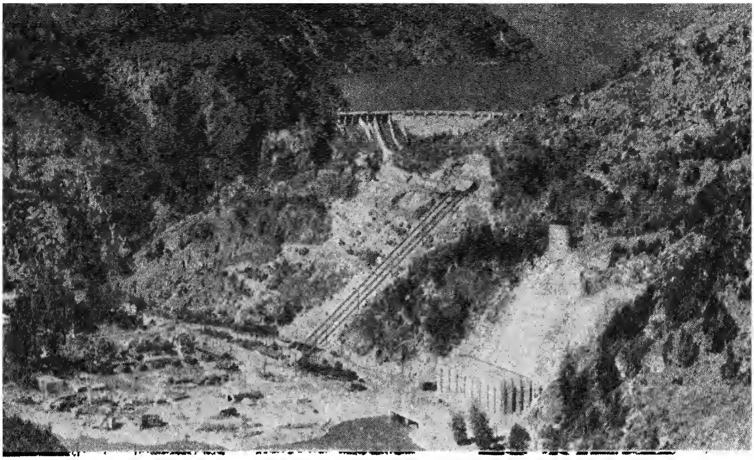


Fig. 459. This is the Diablo Dam and power house on the Skagit River, Washington. Water from the lake back of the dam is carried in a tunnel down to the power house shown in the lower part of the picture. (Westinghouse photo)

horse-power produced at each place. In some of these huge power plants there are single wheels that deliver harnessed energy at the rate of 50,000 horse-power. The largest ever made are used in the Grand Coulee power plant on the Columbia River. These wheels can produce over 100,000 horse-power. Let us get a clear picture of how water is used by these huge wheels.

Usually the first step in harnessing the energy of a stream is to build a dam across a large river, as was done at Keokuk, Iowa, and also at the Boulder Dam. Such a dam holds back the water and creates an artificial lake and a waterfall. Then, as the water drops from the top of the lake to the lower side of the dam, it gives its potential energy to the wheel. In other places, as at Niagara and in the mountains of the West, there is a sufficient natural fall of the water. Dams are needed only to store water and to guide it into canals, tunnels, and pipes that carry it down to the wheels.

The amount of harnessed energy that can be obtained for a water-wheel depends on three factors: The first

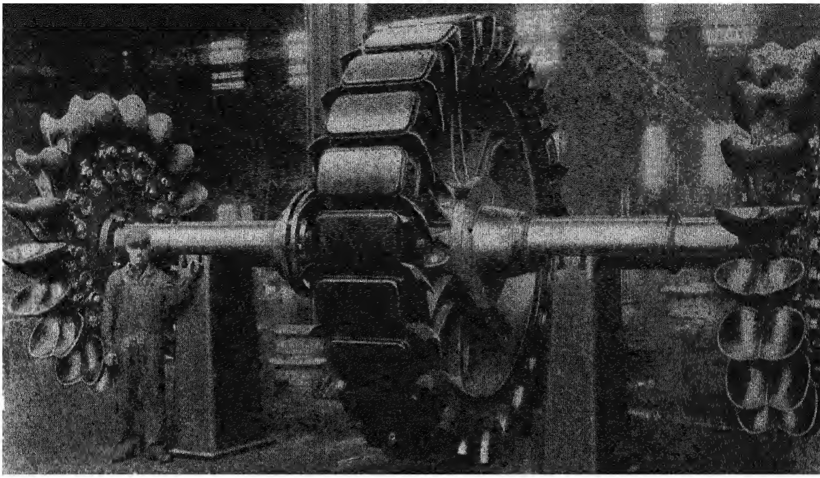


FIG. 460. These two huge Pelton wheels are attached to the axle of an electric generator. With a 700-foot head of water they will turn the armature at a speed of 300 revolutions per minute to produce 5000 horse-power. (Allis-Chalmers photo)

of these factors is the amount of water that goes through the wheel. The second factor is the distance between the water above the dam and the water below the dam. This distance is known as the *head* of water. Each pound of water can do one foot-pound of work for each foot of head it has. Thus, a cubic foot of water (62.4 pounds) with a head of 50 feet possesses 3120 foot-pounds of potential energy (62.4×50). The third factor of such a wheel is its efficiency (see page 223). The efficiency tells how much of the energy of the water is harnessed. Thus, if a water-wheel is 50 per cent efficient, it harnesses only one-half of the energy of the water that goes through it.

The water-wheels in modern power plants are of two types, *Pelton wheels* and *turbines*. The Pelton wheel is a kind of undershot wheel that is most useful where water can be brought from a great height. On the rim of the wheel is a row of carefully curved "buckets" (Figure 460). The wheel with its buckets is placed inside a strong case. The water, under great pressure, is led into the case and

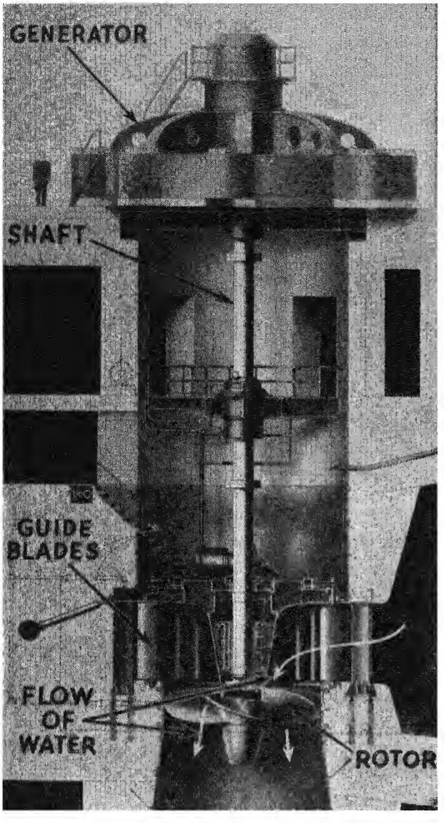


Fig. 461. A 13,500 horse-power turbine with the generator that it drives. The turbine wheel, or *rotor*, is the propeller-like device at the very bottom of the picture. Water enters the turbine from the dark space at the right, through the *guide blades* just above the rotor. Notice how small the man looks standing beside the generator. (Allis-Chalmers photo)

shot against the buckets by a large nozzle, much like that of a garden hose. The shape of the Pelton nozzle is very carefully planned to give the greatest possible speed to the water. The moving water then gives almost all its motion to the wheel which turns at a terrific speed. Some such wheels use water with a head of 2000 feet. As much as eighty-five per cent of the energy of the water is given to the wheel for doing work. Some Pelton wheels produce more than 20,000 horse-power each.

By far the larger number of modern water-wheels are turbines (Figures 461 and 462). Water enters the turbine between guide blades fastened to the stationary part, or case. The guide blades direct the water against the blades on the wheel, or *rotor*. All the passageways for the water, as well as the guide blades and the blades of the rotors, are carefully curved and streamlined to make the turbine as efficient as possible. Some turbines are 95 per cent efficient. In most cases these large Pelton wheels and turbines are connected to electric generators. Thus the harnessed energy of the moving water is sent in the form

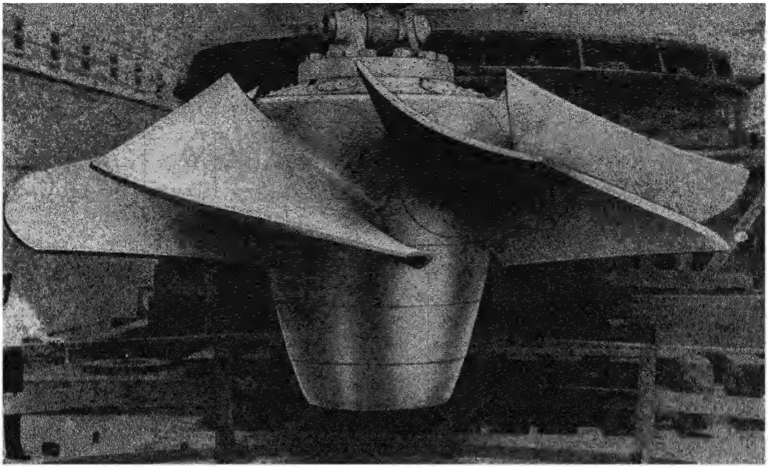


FIG. 462. Lowering a giant turbine rotor into the pit. Notice that in this rotor the blades can be adjusted so that the water will strike them at just the right angle to make the turbine operate most efficiently. (Allis-Chalmers photo)

of electrical current to the homes, factories, and office buildings where it is used.

Only about 40 per cent of the available water power in the United States has been harnessed. At first thought you would wonder why all the water power is not harnessed, because it has such great advantages. But there are two great disadvantages that often outweigh the advantages. Much of the water available for power is in mountainous regions far from railroads and cities. In such places there is little need for harnessed energy, and electric current cannot be economically carried over wires more than about 250 miles long. The second great disadvantage of using water power to generate electrical current is the cost of building the dams, pipe-lines, and power plants.

Self-Testing Exercises

1. Name two types of old-fashioned water-wheels and two types of modern water-wheels.

2. State three differences between the two kinds of modern water-wheels.

3. Turn to your answer that you wrote for Introductory Exercise 5. If it was not well done, answer the question again with your book closed.

4. What three factors determine the amount of energy that can be delivered by a water-wheel?

5. How are turbines built to make them very efficient?

6. State two advantages and one disadvantage of using water power from a river to light a town and run factories on the banks of the river.

7. Why is only 40 per cent of the water power in the United States now harnessed?

Problems to Solve

1. Do you think that wind power or water power is more important in our country at the present time? Give reasons for your answer.

2. Compare the advantages and disadvantages of wind power and water power.

3. The head of water at the Niagara Falls power plants is about 150 feet. (*a*) How much energy would ten cubic feet of water have before going through a water-wheel? (*b*) How much harnessed energy would be obtained from that much water if the wheel were 90 per cent efficient?

4. A turbine that uses a head of 45 feet is 90 per cent efficient and does 50,625 foot-pounds of work per second. How much water passes through it in one second?

5. What interesting facts can you learn about the great water-power plants of this country? Choose one of the plants listed in Table 3 and learn all you can about it. Make a report to your class.

6. Build a working model of an overshot or an undershot water-wheel.

7. How did water power influence the location of cities in the eastern part of the United States during the years when our country was being settled? See what you can find about this problem in history books and encyclopedias.

up and destroy everything around them. The danger of having boilers explode from too much pressure was almost done away with when someone invented a *safety valve*. Figure 470 shows one kind of safety valve. The steam inside the boiler is always pushing against the valve. When the pressure becomes too great, the valve lifts the weight and lets out some steam. In another type of safety valve, the valve is held shut by a spring. Each boiler is also equipped with a steam-pressure gauge, to tell how hard the steam is pushing outward, and a water gauge to show how much water is in the boiler. What would happen to a boiler if there were a hot fire under it and no water in it?

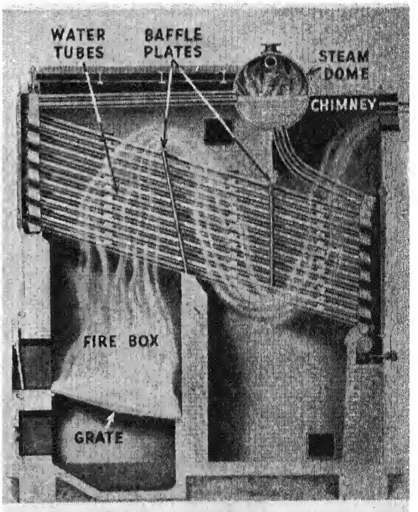


FIG. 469. A water-tube steam boiler

Now let us be sure that you see clearly how a boiler helps harness the energy of coal. The coal holds the energy captive. The chemical energy in the coal does nothing until it is set free by destroying the coal. In the fire inside the boiler, oxygen burns the coal and changes it into something else. Like some bewitched prince in a fairy story, the chemical energy of the coal is freed and changed into heat. The heat is conducted through the steel of the boiler and into the water. There the heat changes the water into steam, whose force can do work.

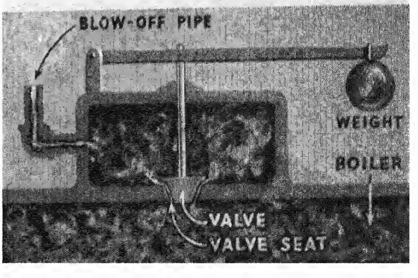


FIG. 470. One kind of steam safety valve

Self-Testing Exercises

1. Why is coal valuable?

2. What are the two main uses to which the energy of coal is put? For which one is more coal burned?

3. Describe the main steps in using the energy of coal to turn wheels.

4. With your book closed, draw a simple diagram of a fire-tube boiler or a water-tube boiler. Use one color or shading to show where the hot gases go, another to show the water, and a third to show the steam. Write a paragraph that explains what your diagram shows.

5. Why is a safety valve found on every steam boiler? Tell how a safety valve works.

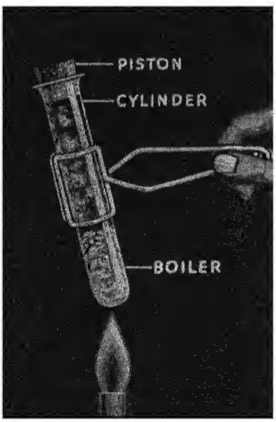


FIG. 471

HOW DOES STEAM RUN AN ENGINE? You have now seen how the energy from coal forms steam. Your next problem is to find out how the steam is harnessed to the wheels by a steam engine. Have you ever heated water in a test-tube and let it push the stopper out? If so, you have seen a steam power plant at work. One end of the test-tube was the boiler; the other was the cylinder. The stopper was the piston for the steam to push.

The steam engine has a cylinder to hold steam while it works, and it has a piston that fits closely inside the cylinder (Figures 467 and 472). But an engine has several parts that your test-tube power plant does not have. First, the piston is connected to a crank so that it will turn a wheel when the steam pushes it. Second, there are pipes and valves to let the steam into and out of the

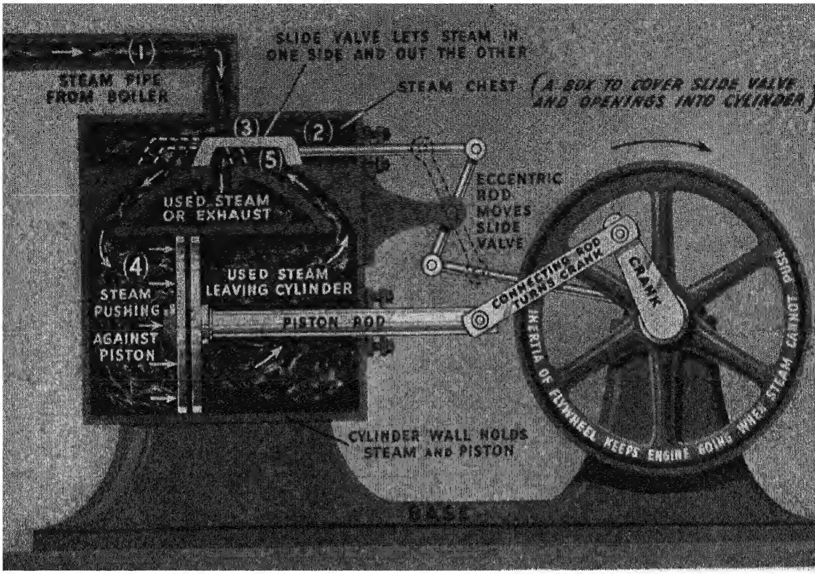


FIG. 472. How a steam engine harnesses energy

cylinder. To push the piston one way, the steam must go in on one side of the piston. To push it back again, the steam must go in on the other side.

Figure 472 shows a common type of engine cut open so that you can see how it works. The steam comes from the boiler through a pipe (1). It enters the *steam chest* (2) and goes past the *slide valve* (3). Then it passes through an opening into the cylinder. There the steam presses against all sides of the cylinder and against the piston (4). The piston is the only part that can move. Thus the steam pushes the piston to the right and turns the flywheel. Soon the piston stops because the crank will not let it go any farther.

Just before the piston stops, the rods attached to the slide valve move the valve to the left to the position shown by dotted lines. Now the steam can escape from the left end of the cylinder and go out through the exhaust pipe (5). At the same time the steam from the boiler can go into the right end of the cylinder and push

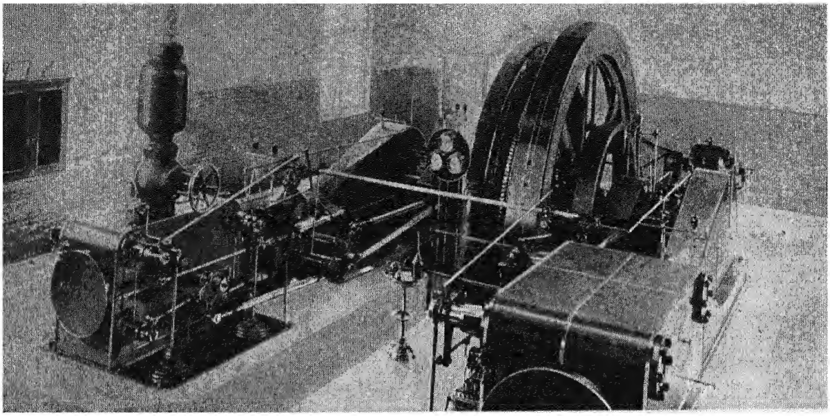


FIG. 473. A steam engine attached to a generator in a light-and-power plant. This engine is one of the most efficient kinds. It has a special valve arrangement invented by a man named Corliss, for whom the engine is named. It also uses the steam twice—once in the cylinder at the left (to which the steam pipe goes) and again in the larger cylinder at the right. The generator and the flywheel are between the two halves of the engine. (Allis-Chalmers photo)

the piston back. When the piston reaches the left end, the slide valve changes, and again the piston is pushed to the right. This action occurs over and over again, sometimes very rapidly and at other times so slowly that you can count the motions of the piston rod. The connecting rod and the crank change the reciprocating motion of the piston rod into the rotary motion of the crank shaft and the flywheel.

There are two points where the piston cannot move the crank and flywheel no matter how hard it pushes. These points are at the ends of the cylinder when the connecting rod and the crank are in a straight line. These two places are known as the *dead points.* There the crank is said to be on *dead center.* One important reason for having a flywheel is to keep the engine from slowing up or stopping on dead center. The flywheel has much inertia. Therefore, when it has been started by a strong push of the piston, it keeps on turning and carries the crank past the dead points. The rods that move the

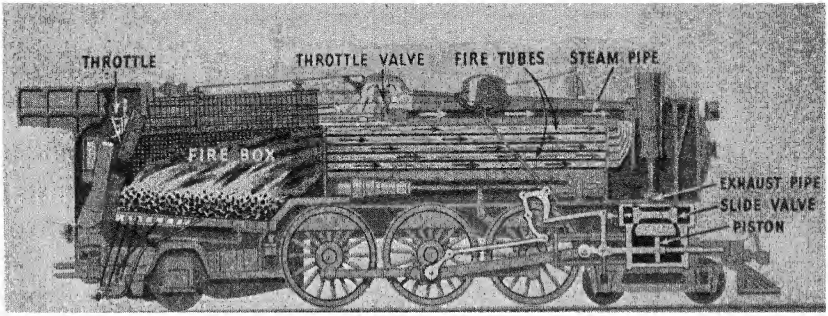


FIG. 474. The "insides" of a steam locomotive

valve may be attached to the engine in different ways. The common way is to have a small crank or eccentric on the crank shaft. This crank is arranged so that it moves the valve rods back and forth at just the right times.

Look at the locomotive in Figure 474. As you have already learned, the larger part of the locomotive is a boiler. On each side near the front is a steam engine. These two engines drive the locomotive. In this picture you can see the cylinder of one of the engines. A large rod connects the piston in the cylinder to the middle driving wheel. A complicated set of rods and levers works the valve in the box just above the cylinder. The engine on the opposite side of the locomotive is attached to its drive wheel in such a way that when one engine is passing its dead point, the other is at the top or bottom, exerting its greatest force. Thus there is no point at which the locomotive can stop with both engines at their dead points.

Do you know why a locomotive or thresher engine "puffs"? It is because the exhaust pipe from the cylinder opens into the smoke-stack. Every time a valve lets the used steam out of one end of a cylinder, there is a puff of steam in the stack. One of the earliest inventors of locomotives thought of this plan to make a strong current of air through the fire.

For over a hundred years the type of steam engine invented by Watt was in use all over the world to provide

power for propelling ships, running factories, and pumping water for our cities. This type of engine is, however, very inefficient. The best of this kind can harness only about 20 per cent of the energy of the fuel used in the boiler. Gradually such engines are being replaced by steam turbines, about which you will learn in the next few pages.

Self-Testing Exercises

1. Tell what each of the following does to help steam turn the flywheel of a steam engine: (*a*) piston (*b*) piston rod (*c*) crank (*d*) slide valve (*e*) slide-valve eccentric.

2. Name two ways in which a locomotive is different from the steam engine shown in Figure 472.

3. Tell the story of some energy from the time it is in coal in a bin until it has changed into the kinetic energy of a locomotive wheel.

Problems to Solve

1. If the slide valve shown in Figure 472 were in the position shown by the dotted lines, how would the other parts of the diagram need to be changed? Make a copy showing the changes.

2. (*a*) How many times does a locomotive puff during one revolution of the drive wheels?

(*b*) How would the slide valve of a steam engine need to be changed to make it run backward?

3. Most steam engines are equipped with *governors* to regulate their speed. How does a governor work?

4. If possible, visit a railroad yard or other place where you can see a steam engine. Ask the man in charge to tell you what each part of the engine does.

5. Make a cardboard or wooden model like Figure 472. Make the slide valve and piston with their rods of separate pieces of material so that you can move them back and forth to help your classmates understand how a steam engine operates. Perhaps you can arrange a crank and crank shaft that will turn and move the slide valve at the proper time.

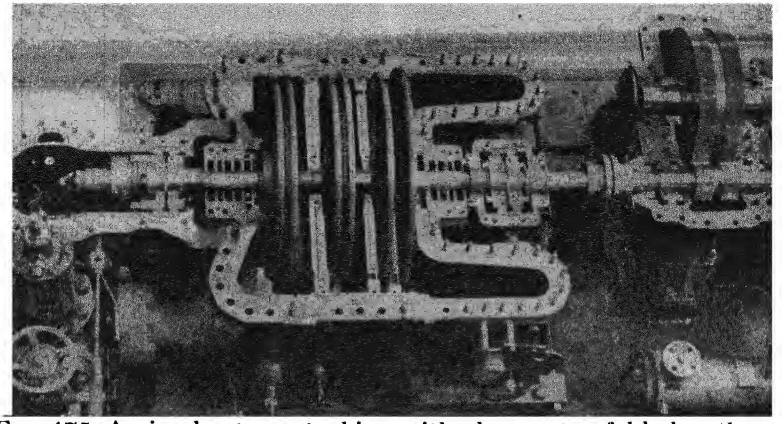


FIG. 475. A simple steam turbine with three sets of blades. Steam enters at the left and strikes each set of blades in succession before it is exhausted and passes out at the right. The upper half of the case has been removed. (Westinghouse photo)

HOW DO STEAM TURBINES WORK? Go into any really modern steam power plant and ask to see the engines. The engineer will probably lead you to a large painted "box." If you insist on seeing the engine, he will tell you that this box is a *steam turbine*. He will also tell you that it is doing the work of 1000 horses in a space about one-tenth as large as a reciprocating engine would need and less than would be needed to care for three horses.

When you learn these facts about the innocent-looking "box," you begin to get interested in it. Nothing very much seems to be happening, except that a kind of steady roar fills the space around you. Looking more closely, you see that a large shaft that seemed to be standing still is really spinning with terrific speed. What makes it spin? Inside the painted metal box is a kind of windmill run by steam. Steam from a boiler enters the box and rushes from one end to the other at speeds up to 1000 miles an hour. The blades of the "windmill" change the energy of this rushing steam directly into rotary motion. You can probably understand the principle of a steam turbine most easily by seeing a model turbine run.

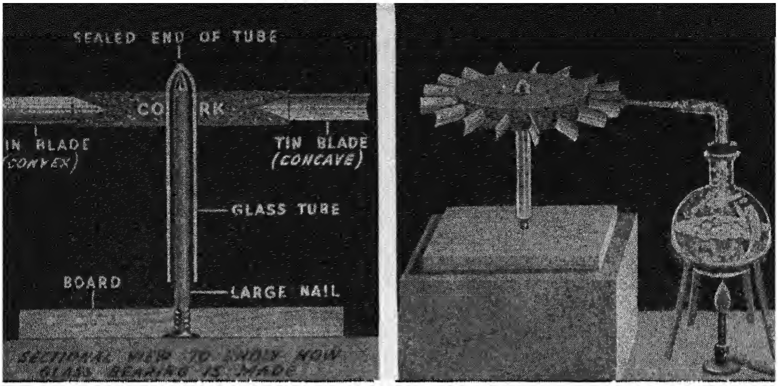


Fig. 476. How to make a model steam turbine

Experiment 48. *How Does a Steam Turbine Work?* Make a model steam turbine as shown in Figure 476. A large cork or cylindrical piece of wood can be used for the wheel. Cut the blades from a tin can and push them into knife cuts in the rim of the wheel. When the wheel is ready and turns very easily, heat water in the flask to make steam. ***Be Careful.*** *Very high pressure in the flask may blow the stopper out and scald someone with the steam and hot water.* Avoid this danger by pressing the stopper in only lightly and using a low flame after the water begins to boil. If your wheel is properly made, the steam from the nozzle should make it spin rapidly.

A turbine like yours was made 300 years ago, before steam engines were invented. However, it never developed very much power; it was considered to be nothing but an interesting plaything. In 1889 Carl De Laval, a Swedish inventor and engineer, wanted to make steam spin a part of a cream separator very rapidly. To do this, he made a wheel very much like yours and arranged several nozzles to send steam against the blades, as shown in Figure 477. By various improvements he soon made a wheel that turned 30,000 revolutions per minute. Today you can see a steam turbine of this type somewhere on the side or top of every large steam locomotive. Usually there is a little cloud of steam escaping from it. It is generating electricity for the lights of the locomotive.

However, the large turbines in power plants and ships are made somewhat differently. Instead of having a single row of blades on a wheel, the shaft carries many rows of blades (Figure 478). The steam strikes the smallest row of blades from the side. Then a row of stationary blades fastened to the cover of the wheel turns the steam so that it gives the second row of moving blades a push. The steam then passes row after row of stationary blades and moving blades until it has lost almost all its energy. From the case of the turbine the steam goes into a cool place where it is condensed. The water is then sent back to the boilers to be used over again.

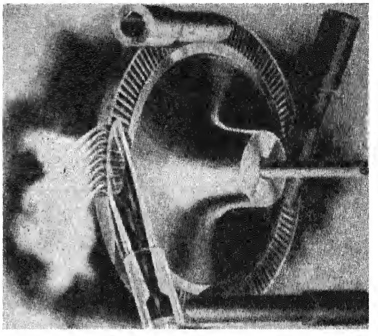


FIG. 477. A De Laval turbine

The turbines that are used to drive a modern ocean liner have more than a million blades. The edge of the wheel travels at a rate of more than 400 miles an hour, and it is so close to the case that uneven heating will make the blades touch the case and be ruined. Several turbines have been built that produce more than 200,000 horse-power from a single machine. Often the shaft that carries the blades of a turbine has on the other end an electric generator. In such machines as much as 100,000 kilowatts (132,700 horse-power) of electric power is produced with only one main moving part for both the turbine and generator.

Turbines have several advantages over reciprocating engines. They take up much less space in proportion to the power they produce, and they run more smoothly.

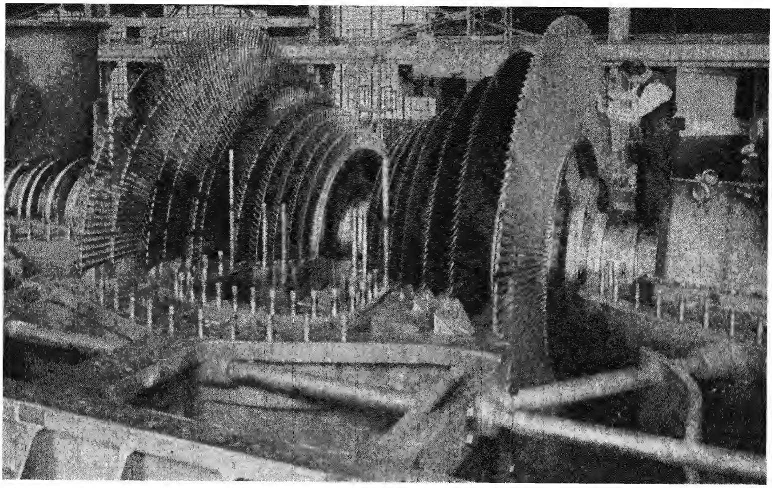


FIG. 478. Here is the inside of a giant steam turbine with sixteen sets of blades. The biggest wheel of blades is about fifteen feet in diameter. The steam enters this turbine at the center and moves toward both ends. (Westinghouse photo)

They are more efficient, for a good turbine power plant uses about 28 per cent of the energy of the fuel. They produce rotary motion directly from the steam; therefore there are fewer moving parts and less friction.

However, as you would expect, there are also certain disadvantages of turbines. They cannot well be run slowly. They run so fast that gears must be used to reduce their speed for pumps and ship propellers. Successful turbines are much more difficult to build than engines. The slightest flaw may cause a huge machine to tear itself to pieces and do a hundred thousand dollars worth of damage. Turbines cannot be reversed, while an ordinary engine runs just as well backward as forward. Can you imagine how ships and locomotives driven by turbines can be reversed?

A number of locomotives have been built with turbines to drive them instead of steam engines. If these prove successful, you may soon see this new kind of locomotive pulling our trains more quietly and efficiently than the

kind that has been in use for more than 100 years. The harnessing of energy through steam is one of the great influences that has made our world different from the world as it was 200 years ago. Take advantage of every opportunity to learn more about steam power and to watch steam engines and turbines at work.

Self-Testing Exercises

1. For what purposes are steam turbines most useful?
2. How does a large turbine use the steam more than once?
3. (*a*) Explain three or more advantages steam turbines have over steam engines. (*b*) Explain two or more disadvantages that they have.

Problems to Solve

1. Make a list of the problems you think the inventors needed to solve in producing efficient turbines.
2. Where does the electric-power company in your locality obtain its electric power? Perhaps you can get permission to visit the plant and learn how the generators are driven.

Problem 4:
HOW IS THE ENERGY OF FUELS HARNESSED BY INTERNAL-COMBUSTION ENGINES?

YOU HAVE seen that steam power plants harness energy in two steps: (1) The fuel is burned to make steam. (2) The steam runs an engine or turbine. This plan requires, in addition to the engines, heavy boilers filled with water and a supply of fuel. Such engines can usually be used only where a heavy power plant is possible: in stationary power plants, in steamships, and in locomotives. Inventors long ago saw that if they could release energy and harness it all in one step, they would have a much lighter harness. What they needed was an engine that burned the fuel in the cylinder instead of in a separate boiler.

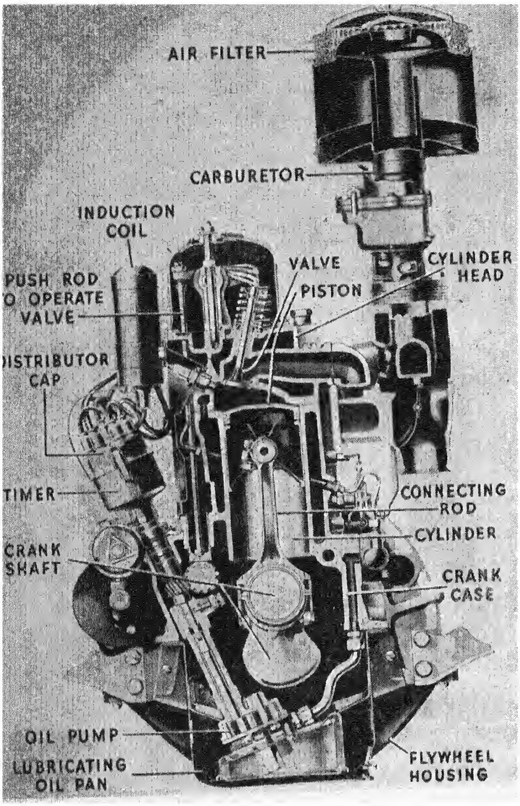


Fig. 479. A cut-away view of a modern automobile engine. This is known as the *over-head valve* type of engine. Find out how the valves are arranged in other types of engines. Also find out the purpose of any of the labeled parts that you do not know about. After you have studied the next few pages, examine this picture again to see how many of the parts you can explain. (General Motors photo)

From about the year 1800 inventors were hard at work on the problem of making an engine that would burn the fuel inside itself so that it would not need a heavy boiler. By 1880 a few engines were being made that burned the fuel in the cylinder. Because they burned fuel inside themselves, they were called *internal-combustion engines*. Today the wide use of automobiles, trucks, tractors, and airplanes proves that this new light harness for using the energy of burning gas is successful.

Watt's early steam engine weighed nearly a ton for every horse-power of energy it harnessed. But a ton of metal in an airplane motor produces 2000 horse-power. About three-fourths of all power produced in the United States is obtained from internal-combustion engines. They are the kind of power machines you see most often. Let us find out how these engines work.

HOW CAN A FIRE PRODUCE A PUSH? To understand how internal-combustion engines work, you must first learn how fuel can be burned in a closed place and how it can give a push because it is burning. A simple experiment will show us how this is possible.

EXPERIMENT 49. *How Does a Mixture of Gas and Air Burn?* Obtain a friction-top tin can about three inches in diameter and five inches high. With a large nail make a hole in the lid and one in the side near the bottom. Enlarge the hole in the side until it is about three-eighths of an inch in diameter. Fill the can with illuminating gas through a rubber tube leading to the hole in the side. Turn off the gas. Remove the tube and immediately bring a lighted match to the hole in the top. The gas should catch fire and burn quietly.

Stand back several feet and watch the flame. Air is entering the hole at the side of the can and mixing with the gas. How does the color of the flame change as the percentage of air becomes greater? What happens just as the flame seems about to go out?

The tin can in this experiment is really a crude internal-combustion engine. The can is the cylinder; the lid is the piston. Gas is the fuel that contains the chemical energy to be released. When just the right percentage of oxygen became mixed with the gas in the can, you probably had what you would call an explosion. This explosion was only a very rapid burning of all the gas that was left in the can. The chemical energy of the fuel changed to heat energy in the gases in the can. The gases include much air mixed with carbon dioxide (CO_2) and water vapor (H_2O) from the burning fuel. See *Book 1,* pages 194-195.

The heat made the molecules of these gases fly in all directions with much greater speed. In other words, the heat made the gases expand very quickly. The result was

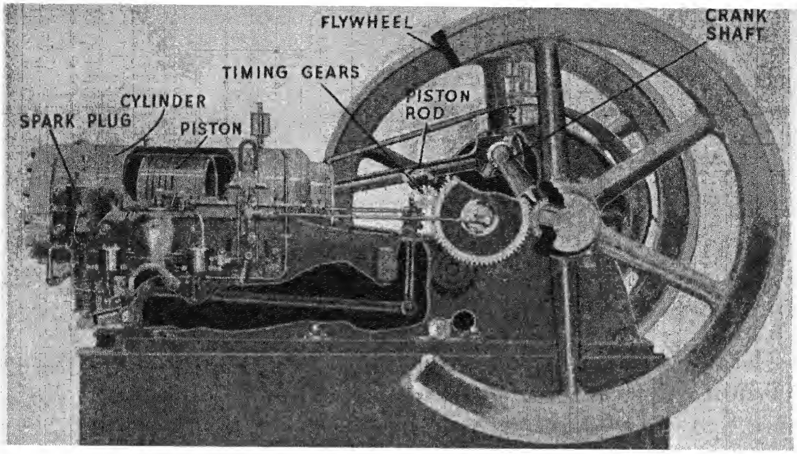


FIG. 480. The parts of a simple one-cylinder gasoline engine

that the can lid flew off with a bang. The chemical energy of the fuel had been changed into the kinetic energy of the moving lid (or piston). Notice again what was done to make the fuel push off the lid: (1) You got the right mixture of air and fuel in the can. (2) The mixture was ignited by the flame. All internal-combustion engines do these same things. In addition, they compress the mixture to get more energy out of it, and they let out the burned gases to make room for a new mixture.

HOW DOES THE ENERGY OF BURNING FUEL RUN A GASOLINE ENGINE? Like a steam engine, a simple gasoline engine has a cylinder, piston, crank, crank shaft, eccentrics, and a flywheel. Find these parts in Figure 480. In addition, the gasoline engine needs two parts that a steam engine does not have: (1) It must have a way to mix the gasoline with the air. (2) It must have a way to ignite the gasoline at the right time. The *carburetor* mixes air and gasoline in the right proportions, and an electric spark sets the mixture on fire.

Let us now follow some gasoline into a one-cylinder gasoline engine and see what it does and how it gives its energy to the engine. Look at Figure 481 to help you

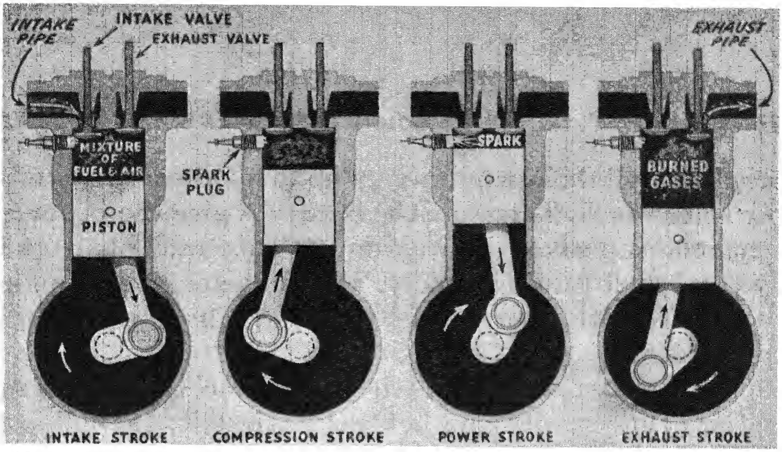


FIG. 481. How a gasoline engine harnesses energy. Be sure that you can explain what happens during each stroke.

understand what happens. To start the engine, the crank shaft must be turned. This may be done by hand (with a crank) or by an electric motor. Let us suppose that the piston is at the top of the cylinder.

(1) INTAKE STROKE. As the crank shaft begins to turn, an eccentric pushes the *intake valve* open. Then the piston moves downward. This leaves a partial vacuum in the cylinder. Air pressure from the outside forces air in through the carburetor. As this air goes rapidly past nozzles in the carburetor, it takes with it the right amount of gasoline in the form of vapor, or a fine spray. Just as the piston reaches the bottom, the intake valve closes. The *intake stroke* has been completed.

(2) COMPRESSION STROKE. On its way up, the piston presses the mixture of gasoline vapor and air into about one-seventh of the space it filled at first. When the piston reaches the top, it has finished the *compression stroke.*

(3) POWER STROKE. Just as the piston stops rising and starts down, an induction coil and other electrical devices make a hot spark leap the gap between the two wires in the spark plug. This spark sets the gasoline on fire, and it burns with great rapidity. The gases in the cylinder get

very hot, and their pressure goes up to hundreds of pounds per square inch. Therefore the hot gases give the piston a tremendous push on its way down. The crank shaft and flywheel start turning rapidly. They have received kinetic energy from the burning of the fuel! The *power stroke* has occurred!

(4) EXHAUST STROKE. As the piston reaches the bottom of the cylinder with the hot gas against it, the *exhaust valve* opens, and the hot gases shoot out through the exhaust pipe. If the exhaust is open to the air, there is a loud bang. Usually, however, there is some kind of a *muffler* to let the gases out more quietly. The inertia of the flywheel and the crank shaft keep them turning, and they push the piston upward. This fourth stroke of the piston sweeps the remainder of the burned gases out of the cylinder. Then the exhaust valve closes, and the stroke has been completed.

However, the engine does not stop. The spinning flywheel and the crank shaft open the intake valve and carry the piston down on a new intake stroke and up on a compression stroke. Then there is another great push during the second power stroke. Our engine is running! It is getting the energy to run directly from the gasoline. The series, or *cycle*, of four strokes is repeated for every push the piston gets. Because of this method of operation, the ordinary gasoline engine is said to be a *four-stroke cycle* engine or, for short, a *four-cycle* engine. A somewhat different kind of engine has a two-stroke cycle; every downward stroke is a power stroke. Many two-stroke cycle (or two-cycle) engines are used on motorcycles, outboard motorboats, washing machines, and home electric generating plants.

As you have seen, the piston of a four-stroke cycle

engine gets a push only once in four strokes. As a result, the power from a single cylinder is rather irregular, and the flywheel must be quite heavy to smooth out the jerks. To get more power and an even flow of power, most internal-combustion engines have four or more cylinders. Six and eight cylinders are now most common in automobile engines. Twelve-cylinder automobile engines and thirty-six cylinder airplane engines are not uncommon.

As you can easily understand, the parts of the gasoline engine that you have seen at work must be helped by many other parts to keep the engine working successfully. A modern automobile engine has at least four systems of parts. The first is the *fuel system*. The gasoline for fuel is usually carried in a tank at the rear end of the car. A pipe leads from this tank to a fuel pump. The pump keeps a little tank in the carburetor full of gasoline all the time. Usually there is a little cup and screen between the tank and pump to remove water and dirt from the fuel before it reaches the carburetor.

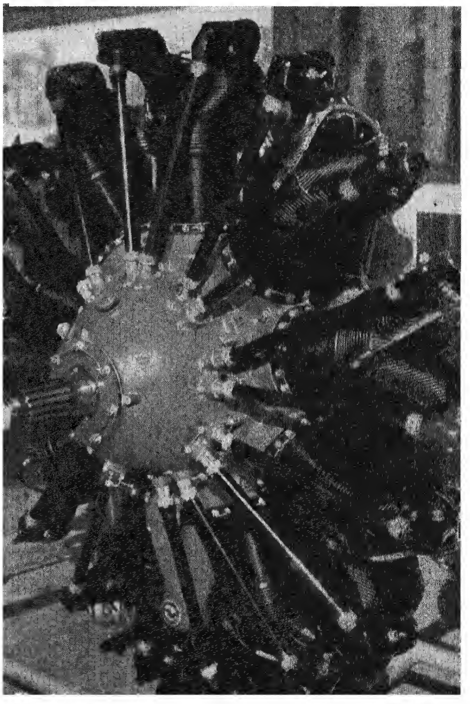


FIG. 482. A nine-cylinder airplane motor (R. B. Hoit photo)

An *electrical system* serves several useful purposes. Most important, of course, is the production of a spark in each cylinder at the right moment. A sixteen-cylinder

motor may run at the rate of 3000 revolutions per minute. In that time there must be 24,000 separate fires started in the cylinders, each one at just the right time. A *distributor* with wires sends electricity to each spark plug at the proper time. In addition, the electrical system has a *starting motor* to start the gasoline engine, a generator to make the electric current while the engine is running, a storage battery to furnish current when the engine is not running, and lights for illumination.

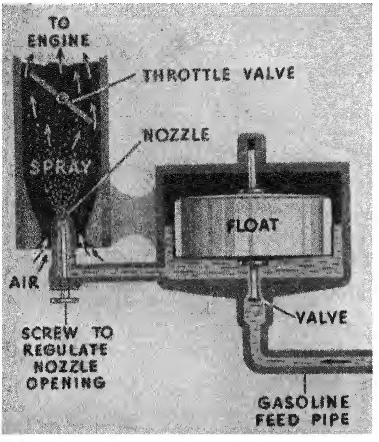


FIG. 483. This simplified drawing of a carburetor will help you understand how the carburetor works.

All the moving parts of an engine must be well oiled to keep them from wearing out. Oil is also very important to make the pistons air-tight in the cylinders and to reduce the wear on the piston and on the walls of the cylinder. The *lubrication system* keeps the engine oiled. Its main parts are: a reservoir of oil in the bottom of the engine, a pump, and pipes leading to all the parts that need oil.

You have seen that the burning of gasoline in the cylinders produces very high temperatures. Some of this heat is used in pushing the pistons, but no one has found a way to use all of it. If this extra heat were left in the engine, the cylinders would soon get red-hot and be ruined. To prevent such damage is the work of the *cooling system*. A hollow space around each cylinder, the *water jacket*, is filled with water. A pipe leads hot water from

these water spaces to many copper tubes in the *radiator*. As this hot water passes down through the radiator, heat is conducted from the water into the air. A fan keeps the hot air moving away, and the cooled water returns to the motor for more heat. A water pump keeps the water circulating through the radiator and the engine.

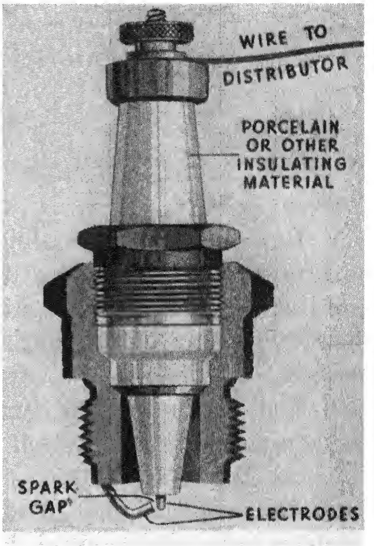


FIG. 484. The parts of a gasoline-engine spark plug

From this brief description you can see that an automobile engine is a very intricate and carefully made machine. Each one of hundreds of parts must be in good condition and exactly adjusted for the engine to run properly. Only an expert engineer or mechanic can tell exactly what the parts are for and how they must be adjusted, but you can understand why the engine runs and how it gets the energy from the gasoline in the tank. The time may come when you will have an automobile of your own. If you understand how it works, you can handle it more intelligently and avoid unnecessary damage to it. Many people ruin automobiles and cause themselves much expense because they do not understand how they work.

Self-Testing Exercises

1. Why is an automobile engine called an internal-combustion engine?

2. Write down from memory the four strokes of a piston in

a gasoline engine. After each one tell briefly what happens during the stroke.

3. (*a*) During which stroke or strokes must the intake valve be open? (*b*) During which stroke or strokes must the exhaust valve be open? (*c*) During which stroke must both be closed? In each case tell why.

4. Why is there greater pressure on the piston of an internal-combustion engine during the power stroke than during the compression stroke?

5. What advantages are there in having several cylinders in an automobile rather than one?

Problems to Solve

1. Examine an automobile engine. Make a list of the important parts you can identify. Also make a list of the parts you find but whose use you do not understand. If you cannot name them, you may describe them briefly or tell where they are located.

2. Visit an automobile garage or an automobile salesroom to see as many of the important internal parts of a car as you can.

3. (*a*) What advantages would a gasoline delivery truck have for milk delivery to city homes? (*b*) What advantages would a horse-drawn truck have?

4. (*a*) How many pushes does the piston of a one-cylinder steam engine receive during one revolution of the crank shaft? (*b*) How many cylinders must a gasoline engine have to get the same number of pushes?

5. Make a special study of one of the following and report to your class:

a) Two-stroke cycle (two-cycle) gasoline engines
b) Airplane engines
c) The cooling system of an automobile
d) The lubricating system of an automobile
e) Uses of gasoline engines
f) Tractors and their uses
g) The ignition system of an automobile

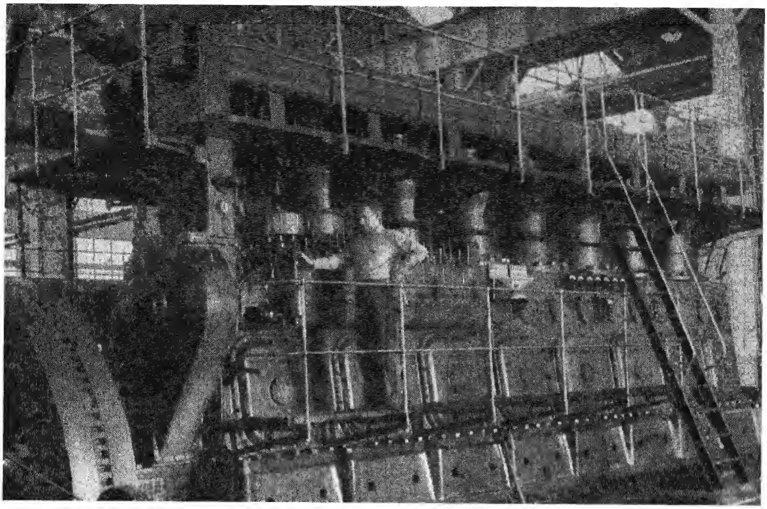


FIG. 485. An eight-cylinder Diesel engine in the power-and-light station at Russell, Kansas. This giant engine can furnish 1600 horse-power. (Nesmith and Associates photo)

HOW DOES A DIESEL ENGINE WORK? Have you seen a modern streamlined train thundering along the track faster than most steam trains go? Many of these trains are driven by Diesel engines, and Diesel engines are also used in small power plants, trucks, tractors, and ships. What are they, and how do they work?

About 50 years ago Dr. Rudolph Diesel, a German scientist, got the idea that he could make an internal-combustion engine that would work without spark plugs. About 1897 he produced one that was successful. This kind of engine is much like the ordinary gasoline engine, except that it does not have spark plugs or a carburetor. It burns very cheap kinds of oil and, to do the same work, uses fewer gallons of fuel than a gasoline engine. A ton of oil burned in a Diesel engine does as much work as four tons of coal burned in a steam locomotive.

The Diesel engine gains these advantages through two important features: First, the air that enters the cylinder during the intake stroke is compressed into about one-

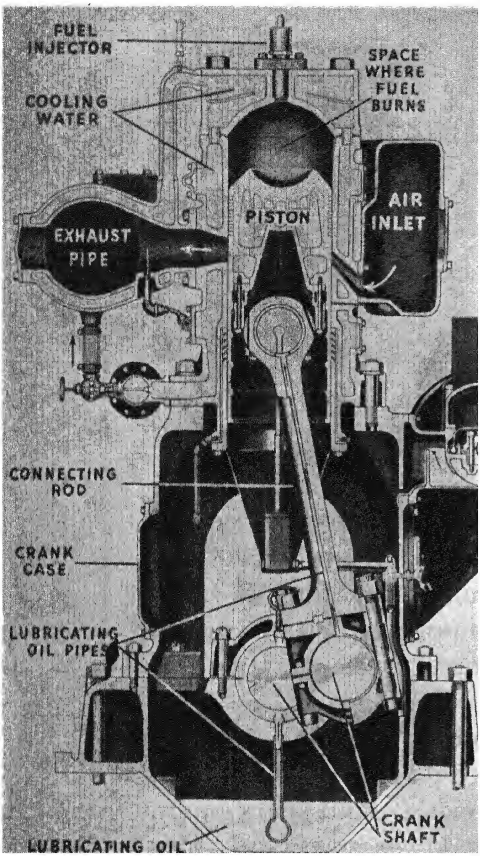


Fig. 486. A cross-section view of a Diesel engine. Compare it with Figure 479 to see how much alike the Diesel and the gasoline engines are. However, this is a two-cycle engine in which the piston opens and closes the intake and exhaust openings as it moves up and down. (Fairbanks-Morse photo)

fourteenth of the space it filled at first. (You remember that a gasoline engine compresses its vapor to only about one-seventh.) Compressing air heats it, as you know, and this great compression causes the temperature to rise to more than 800° F. Second, just as the piston reaches the top of its stroke, a small but very powerful pump sprays a tiny bit of oil into the hot air. Almost instantly the oil is vaporized and begins to burn. The heat from the burning oil expands the air and makes the pressure in the cylinder head still higher. This, together with the expansion of the burning oil vapor, drives the piston down during the power stroke.

Diesel engines are usually much heavier than gasoline engines, but they burn such cheap fuel and so little of it that they are widely used on heavy trucks and tractors as well as in stationary power plants. They are also being used in locomotives because they do not need to stop

so often for fuel and water. As you have already learned, a Diesel engine uses only one-fourth as many pounds of fuel as a steam engine of the same power.

From what you have just read, you can see that internal-combustion engines have a number of advantages over steam power plants. They are very much lighter to carry around, and they use a convenient form of fuel. They also harness a higher percentage of the energy in the fuel. Gasoline engines are about 30 per cent efficient, and Diesel engines may be 38 per cent efficient. In addition, they can be started and brought to full speed quickly, instead of waiting a long time to "get up steam."

On the other hand, internal-combustion engines must be very exactly adjusted, or they will not run at all. Most internal-combustion engines cannot run backward. To reverse the direction of their force, a complicated set of gears is necessary. They tend to "die" if an overload is put on them, while a steam engine just keeps on pulling. From their wide use you can see that for certain purposes the advantages far outweigh the disadvantages.

Self-Testing Exercises

1. (*a*) When is fuel put into the cylinder of a Diesel engine? (*b*) How is the fuel put in?

2. How is the fuel ignited?

3. State two other differences between Diesel engines and ordinary gasoline engines.

4. State three reasons why internal-combustion engines are used instead of steam power plants for automobiles.

Problems to Solve

1. Read in some reference book the story of Dr. Rudolph Diesel's life and of his experiences with his engines.

2. Why do you think gasoline rather than Diesel engines are used in automobiles?

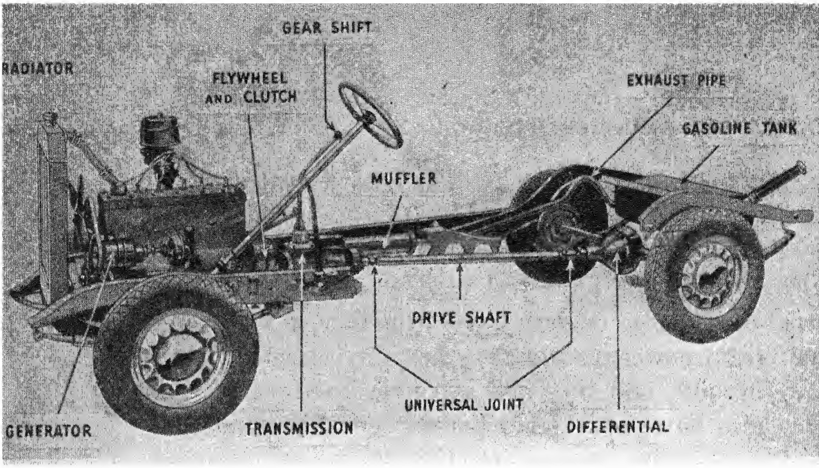


FIG. 487. How the power is transmitted from the engine to the rear wheels of an automobile

Problem 5:

HOW IS HARNESSED ENERGY TRANSMITTED?

A PATIENT teamster has not completed the harnessing of his team until the straps or chains from the harness are hooked to the singletrees, the singletrees to the doubletrees, and the doubletrees to the plow. By these devices the force of the horses' muscles is transmitted to the device that does the work of breaking up the soil. In the same way the energy brought under control by power machines must be transmitted to other machines that do our work. Often the energy must be carried long distances, and the direction or rate of motion changed. This work of transmitting harnessed energy is usually done in one of three ways: by mechanical devices, by compressed air, and by electric current.

In Unit 4 you learned of some mechanical devices that transmit force. When these devices cause things to move, they transmit energy from one place to another. Ropes, belts and pulleys, chains, shafts, and gears are used to transmit the energy harnessed by engines. An automobile is a good example of the use of gears and other mechanical devices to transmit power.

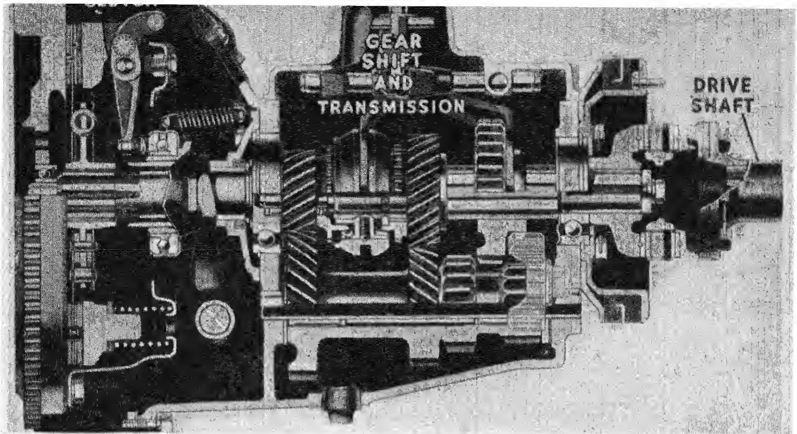


FIG. 488. A cutaway view of the clutch and transmission gears of an automobile (Ford Motor Co. photo)

HOW IS POWER TRANSMITTED FROM AN AUTOMOBILE ENGINE TO THE REAR WHEELS? Figure 487 shows the parts that transmit power from the gasoline engine, or motor, to the rear wheels. Let us follow the power step by step from the flywheel of the engine to the wheels. We come first to the *clutch*. The clutch has three main *disks*. Two of these disks are attached to the flywheel and are turning all the time the engine is running. The third disk is between the other two and is attached to a shaft that leads toward the rear wheels. A spring presses the two outer disks very tightly against the middle disk. Both are covered with a material that has a great deal of friction. Therefore the middle disk must turn with the flywheel and transmit power along its shaft. In this position we say the clutch is "in."

To throw the clutch "out," the driver of the car pushes down on a foot pedal. This moves a lever that separates the two outer disks. They no longer press on the middle disk, but turn freely, while the middle one can stand still. Thus, by throwing the clutch "out," the engine is disconnected from the drive shaft.

Next we come to the *transmission gears*. These gears are all in a metal box, or gear case. In the top of the case is

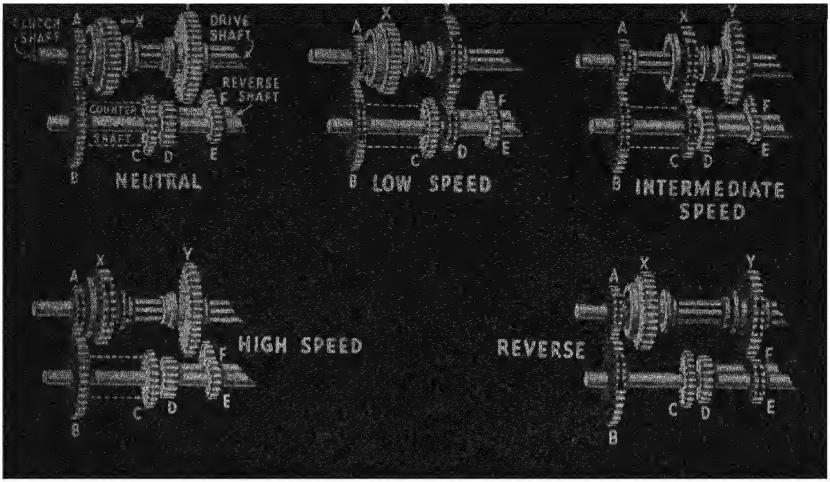


FIG. 489. See if you can explain this drawing of the gear shifts. The letters have been put on the gears to help you explain what happens.

a rather long transmission lever that we call the *gear-shift* lever. The gears allow the engine to run at its best range of speed while the car runs forward slowly with great force (low gear), more rapidly with less force (intermediate, or second gear), or very rapidly with much less force (high gear). The gears will also drive the car backward while the engine runs just as it does when the car is moving forward. By throwing the clutch out and moving the gear lever into proper position, the driver can slide the gears along their shafts and use the set that meets his needs.

While the car is standing still with the clutch in, some of the gears are moving, but their teeth are not touching any of the gears on the drive shaft. In starting, the driver usually uses low gear and then second gear, until the car is moving quite rapidly. Then he shifts to high gear for traveling along the road. When he comes to a very steep hill, he must shift back to low gear so that the engine can run rapidly and move the car with greater force but more slowly. From Figure 489 you can understand how the gears are used to move the car at different speeds in relation to the engine's speed. In each case the gears that

are being used are shaded more darkly than the ones not in use. Notice that in high gear one gear slips inside another, and the two parts of the drive shaft turn together.

At the rear end of the drive shaft is a small gear wheel. The spiral teeth of this small gear press against the spiral teeth of a large gear set at right angles to it. The large gear is attached to the shafts, or axles, that turn the rear wheels. Where the axles of the two wheels meet in the middle of the car is a complicated joint with about six other gears in it. This joint is the *differential*. It allows one wheel to turn faster than the other in going around corners.

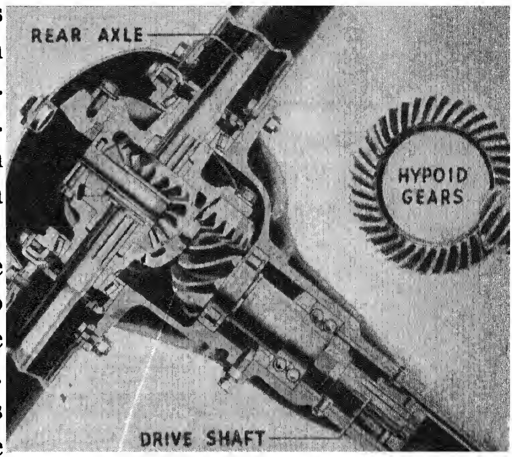


FIG. 490. An automobile differential. Find out what is meant by *hypoid* gears. (General Motors photo)

Let us now follow the energy from the gasoline to the rear wheels. In the cylinder the gasoline burns. Its chemical energy changes to heat energy, expands the gases, and makes them force the piston downward. The piston pushes the connecting rod. The connecting rod pushes the crank shaft around, and the crank shaft turns the flywheel. The flywheel turns the clutch disks and the shaft leading to the transmission case, and the gears turn the drive shaft that goes back to the rear of the car. By means of gears the drive shaft turns the rear axles that turn the rear wheels. The wheels move the car forward. When you start on your next auto trip, you can better understand how complicated a machine you are riding in.

Self-Testing Exercises

1. Why does an automobile have a clutch?
2. Why does an automobile have several sets of gears in the transmission case?
3. An automobile is standing still with the engine running. Tell, step by step, what happens until the rear wheels begin to turn.
4. When an automobile is moving along a level road, what would happen if someone held the clutch pedal down? Explain.

Problems to Solve

1. When a car is standing still, shifting into gear without throwing the clutch out may stop the engine or break something. Explain why.
2. If an automobile were driven by a steam engine, what parts of the transmission system could be eliminated?
3. What changes have been made in the transmission systems of the newest automobiles? Talk to salesmen and read recent science magazines. Then report to your class.

HOW IS COMPRESSED AIR USED TO TRANSMIT ENERGY? Have you ever passed where a new building or bridge was being erected and heard the noisy clatter of a riveting machine? These noisy machines are driven by compressed air. Have you ever noticed how the brakes of a whole train are "set" or released when the engineer moves a small lever? Compressed air works the brakes. Without air brakes our long freight and passenger trains could not be handled safely. Compressed air drives the sand blast that cleans the dirty faces of buildings in the city and smooths and polishes the rough iron and steel castings in foundries. Compressed air pushes the water out of caissons and tunnels.

In all these uses compressed air is really serving to transmit energy that was originally harnessed by a

FIG. 491. This workman is using a compressed-air hammer to spread these bolt heads in a locomotive boiler after they have been screwed in as far as necessary. (Nesmith and Associates photo)

gasoline engine, a steam power plant, or a water-wheel. Compressed air is very useful to us because it both stores energy and transmits it. It can store energy because it is elastic and acts like a spring. Potential energy is formed when the air is compressed. It remains stored in a tank until it is released to do work.

The compressed-air riveter, the air brakes of a train, and the air drill are good examples of the storage and transmission of energy by compressed air. Near a building on which a riveter is being used, you can find some kind of large air pump or air compressor. This pump is often driven by a gasoline engine. Connected with the pump is a storage tank for the air. From the tank a pipe leads up to the steel frame of the building. The gasoline engine obtains energy from gasoline to fill the tank with air under pressure. This air moves through the pipe to a heavy piston. When the workman opens a valve, the air makes the piston move back and forth very rapidly to spread the

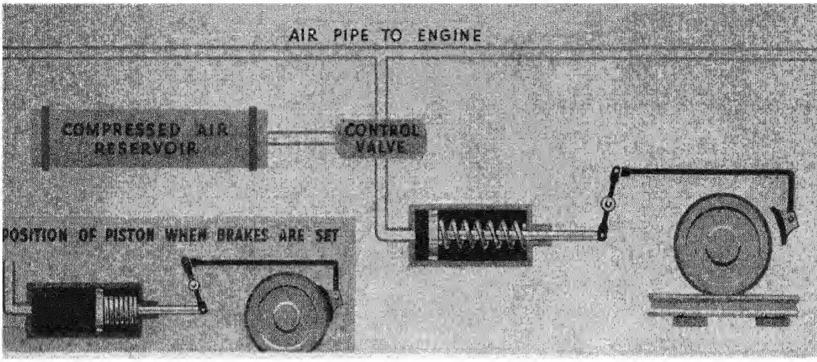


FIG. 492. How the compressed-air brakes on a train operate

ends of the red-hot rivets. Thus, the compressed air transmits energy from the gasoline engine to the rivets high on the frame of the building. In a similar way compressed-air machines operate drills in mines and stone quarries, chisels for carving stone and breaking up pavements, and many other devices.

The air brakes on trains operate so successfully because each car carries, in a tank of compressed air, the energy to set its own brakes. This energy is obtained in the first place from a small steam engine on the locomotive. The piston in this engine operates an air pump that you can see on the side of a locomotive. The air pump fills a large tank on the locomotive to a high pressure. From the locomotive an air-supply pipe leads back under the cars from car to car, and is connected to the tank on each car.

The heart of the car's air brake is a complicated control valve. Whenever the air pressure in the supply pipe falls too low, this control valve sends air from the car's air reservoir against a piston that sets the brakes. To set the brakes, the engineer turns a small lever near his seat. This shuts off the main supply of air and lets air out of the pipe. Almost instantly every control valve in the train begins to send air against its brake piston, which sets the brakes on the wheels of that car. The same thing

happens if the train breaks in two. A connection breaks, the air escapes from the supply pipe, and the brakes are set automatically. After a train has stopped, you can often hear the hiss of air released from brake cylinders so that the train can be started again.

Today, many trucks and buses, as well as trains, are equipped with compressed-air brakes. In these brake systems compressed air stores some of the energy of the engine and transmits it to the brakes when they are needed. Thus the engine can do for the driver most of the work of putting on the brakes to stop the car, and can do it more efficiently.

Self-Testing Exercises

1. Name four uses of compressed air. If you have seen compressed air being used in any of these ways, tell what you saw.
2. Tell how a compressed-air riveting hammer high up on a building gets the energy to do its work.
3. Explain briefly how compressed air is used to help stop a train.
4. Why is it advisable for each car of a train to have its own pressure tank to operate the brakes?

Problems to Solve

1. Find out how an air compressor works to operate a drill or a riveter.
2. Read in reference books about the use of compressed air in tunnels and caissons. What is the great danger for workmen in such places?
3. How are liquids used for transmitting force? Read about hydraulic presses, brakes, jacks, and similar devices. Examine a barber's or dentist's chair and learn how it works. Keep your eyes open for hydraulic elevators for automobiles at service stations.

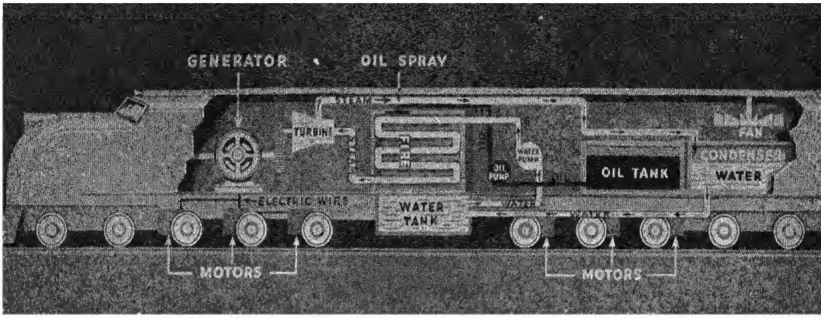


FIG. 493. Some of our newest streamline trains are run by electricity generated in the train by Diesel engines or steam turbines, as above. This diagram will help you understand how such trains operate. See if you can explain two things about this kind of locomotive: (1) the changes in the kinds of energy, and (2) how the power is transmitted. Gears are used to connect the motors to the wheels.

HOW IS ELECTRIC TRANSMISSION OF POWER USED? In your study of Unit 8 you learned that electric current is one of our most useful ways of transmitting power. Some kind of energy-harnessing machine drives a generator that makes electric current. The current goes out over wires and often through transformers until it reaches the place where it is needed. There lamps may change the electric energy into light; toasters, irons, and heaters change it to heat; and motors change it back into kinetic energy to run all sorts of machines.

Electric transmission has taken the place of many belts, pulleys, and shafts in factories. Engineers find that they can use a motor on each machine more safely and economically than they can use belts and pulleys to bring the power to the machine. Several important advantages are gained by using it to drive ships and Diesel locomotives. When electrical transmission is used for these purposes, a steam turbine or a Diesel engine drives a generator. Wires carry the electric current to electric motors that turn the propellers or drive wheels. This plan allows the power machines to be put in the most con-

venient place for them and to be run at their most efficient speed. Another advantage of this plan is that the motors, and therefore the ship or locomotive, can be reversed simply by throwing a switch.

Self-Testing Exercises

1. Name several examples of the use of electric currents for power transmission.
2. Describe the simplest possible arrangement for using electrical transmission in the place of some other kind of transmission.

Problems to Solve

1. Could electric current be used in the place of compressed air to drive a riveter? To operate brakes on a train? Give reasons for your answer.
2. What disadvantages can you find in the electrical transmission of energy?

Problem 6:
WHAT SOURCES OF ENERGY WILL WE USE IN THE FUTURE?

WHAT IS THE REAL SOURCE OF THE ENERGY THAT RUNS OUR MACHINES? You now understand how man has gone out into the world and harnessed the energy he found there. He has harnessed the energy of the wind with sails and windmills. The water of streams running down to the sea turns his giant water-wheels. Energy from fuels runs his steam power plants and internal-combustion engines. But have you seen that all the energy harnessed by these machines comes from one real source? Let us first see where the wind gets its energy. What makes it blow? The wind blows because the air at some place has become warmer than at some other place. Cool, heavy air pushes the warmed air up. The current of air moving along the earth is the wind. What starts the wind and keeps it blowing? It is really the sunlight warming the

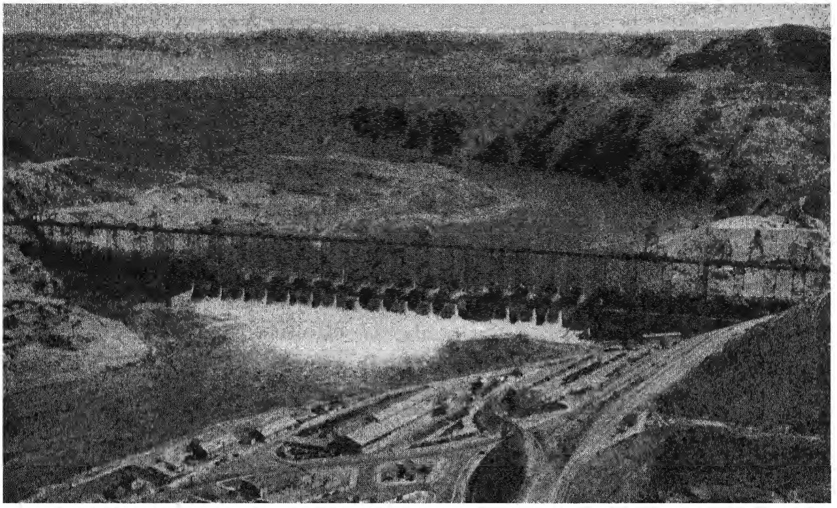


FIG. 494. The Grand Coulee Dam of the Columbia River. When completed, this dam will be the greatest man-made structure in the world. It will contain two and one-half times as much concrete as Boulder Dam, will make a lake 150 miles long, and will be able to develop 2,646,000 horse-power. (U. S. Bureau of Reclamation photo)

earth that makes the wind blow. The energy of the wind comes from the sun!

And the water! Where did it get its energy? It has potential energy because it is lifted up high above the level of the ocean. It can do work running down again. The water was evaporated by the heating effect of the sunlight. Then the wind blew the water vapor to great heights, from which it fell on the highlands. The energy for our water power also comes to the earth in the sunlight.

You have probably guessed the rest of the story already. The sunlight shone on the leaves of trees millions of years ago. The green leaves caught the radiant energy and stored it in the wood as chemical energy. Through long ages the wood was buried and gradually changed to coal. We mine the coal and use the energy. Similarly, the energy in petroleum came to the earth in sunlight. It was captured, probably by tiny green plants in the

ocean. The plants were eaten by animals. The bodies of the tiny animals, buried in the sand and mud of the ocean bottom, each gave out a tiny amount of oil. This oil is the petroleum that collected in the great oil fields. From the petroleum we get gasoline and other fuels. Thus the energy of the ancient sunlight takes us driving in the sunlight of today.

The winds will blow and the rivers will run down to the sea so long as the sunlight and the mountains remain. Experts say that our coal supplies in America will not last for more than 4000 years. If we share with other countries and continue to use more and more ourselves, they will not last more than 1000 years. Coal is not being made today, and we are using up the store that was produced in past ages. About petroleum no one seems to know. Most people, however, believe that the oil fields will not last as long as the coal mines. What then?

WHAT ARE THE POSSIBLE ENERGY SUPPLIES OF THE FUTURE? Could we get more energy from the wind? That is quite possible. Someone has calculated that a wind blowing 30 miles per hour, a mile wide, and 100 feet deep could produce 100,000 horse-power. But what a forest of windmills we would have to put up! And how would we store such immense amounts of energy for the days when the wind does not blow?

Could we harness all the water power and use it instead of coal and oil? Not more than one-third of the water power of the United States has been put to work. But even if it were, engineers point out that there would be only half enough for the present power needs of the country. And much of the water power is so far away from cities that the energy cannot be transmitted to places where it is needed.

Could we harness the waves and the tides? Undoubtedly much energy is going to waste along the ocean shores. A British scientist estimates that the tides along the shores of Great Britain have 12,000,000 horse-power of energy. But no really successful plan of putting the tides to work has been invented. They come and go; so a power plant that depended on them could not run continuously. Like wind power, a way of storing the energy would be needed. Like water power, tide power would have to be used within a few hundred miles of its source.

Can we find new supplies of fuels? When coal and oil give out, we would need to turn to fuel that grows each year. Cornstalks and straw, rapidly growing trees, and alcohol from grains and vegetables are possible sources of energy. In recent years there has been much talk of using alcohol in automobile engines to save gasoline. However, alcohol from grain costs much more than gasoline. And if the whole corn crop of the country were made into alcohol, there would be only half enough for our present needs.

Can scientists destroy the atoms of matter and get energy? One great scientist has said that the energy in one-half pound of matter, if all released, could drive an ocean liner across the Atlantic Ocean and back again. But, as yet, only tiny bits of this energy have been obtained. And each time they do it, scientists have to use much more energy than they get back.

Can the sunlight itself be put to work? Enough sunlight falls on the earth in one minute to drive all man's machines for a year. The light that falls on 200 square miles of American desert has energy enough to supply the whole United States. But how can we capture this energy? That is the difficulty. Men have been at work

on the problem for a long time. Some of them built great reflectors to heat oil and boil water. Engines have actually been run in this way. Some men are seeking a way to change light directly into electric current. They have really run a few tiny electric motors by such power. Other men are trying to have light carry on chemical changes that will store its energy. As yet, however, they have not been able to discover a method that works as well as the leaves of green plants.

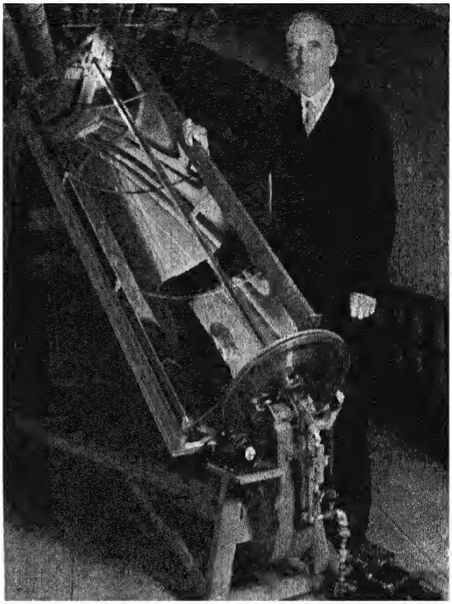


FIG. 495. This machine was invented to use the energy of the sunlight for running machines. It was actually able to run the small engine that you see in the lower part of the picture.

What is the answer? No one knows. Certainly we are going right on using water power and coal and oil. Gradually, as fuel becomes more scarce and expensive, other kinds of fuel will be obtained from plants. Perhaps some one will discover a good way to store energy from the winds and tides. Perhaps some one will learn to capture the energy of sunlight in an efficient manner.

Not long ago scientists discovered how to get energy from atoms of uranium and plutonium. But so far this atomic energy has been used only for destruction. Someday we may learn to use it for the benefit of mankind.

Self-Testing Exercises

1. Explain as well as you can how the energy of the sunlight gets (*a*) into the wind, (*b*) into water in mountain streams, (*c*) into coal, (*d*) into gasoline.
2. Do you think that there is likely to be a permanent shortage of fuel before you die? Give your reasons for your opinion.
3. Make a list of the possible energy supplies of the future. After each one, tell why it is not used now.
4. Why are inventors trying to capture the energy of sunlight directly?

Problems to Solve

1. Trace the energy from the sunlight to an electric bulb, assuming that it passed through a water turbine.
2. Trace the energy from the sunlight to an electric motor, assuming that it passed through a steam turbine.
3. Trace the energy from the sunlight to the wheels of an automobile.
4. How have men tried to harness the energy of the sun? Look up "Solar Engines" in encyclopedias.
5. How have men tried to harness the tides? See what you can find on this topic in reference books.

LOOKING BACK AT UNIT 9

Energy from the sun reaches the earth and is used to do our work.

1. List the important supplies of this energy on the earth that have been successfully harnessed. For example, one supply would be "The energy of fuels."
2. State in one sentence how the first supply of energy you name has been harnessed. Then do the same for each of the others.
3. List the three most important ways of transmitting harnessed energy.

ADDITIONAL EXERCISES

1. Read in reference books to find the answer to one of the following problems.

a) How did a Newcomen engine use air-pressure?

b) What great improvements did James Watt make in steam engines?

c) What were the main difficulties of the early inventors of steam engines?

d) How were the first locomotives constructed?

e) How was steam made to drive the first steamboats?

2. How can a steam engine use steam twice? Read about compound steam engines. (See Figure 473.)

3. How is a *condenser* used with some steam engines? Read how James Watt invented the condenser and learn what you can about modern steam condensers.

4. Learn how a carburetor is constructed. Read all you can find in reference books, and examine real carburetors. Talk with auto mechanics about them.

5. How are the parts of the electrical system arranged to produce sparks at just the right time in each of the different cylinders of an automobile?

6. What are *super-chargers* on gasoline engines? Why are they used? How do they work?

7. How many power strokes occur during one revolution of a four-cylinder four-cycle gasoline engine? Of an eight-cylinder engine? Of a twelve-cylinder engine?

8. What disadvantages are there in having many cylinders in an automobile engine?

9. Find out how the thermostat controls the temperature of the water in an automobile engine.

10. The pumps on fire trucks and in many other places have *air domes*. Of what value are these air domes?

11. How does pressure change the boiling point of water? Learn, if you can, how hot the water in a boiler gets when the steam pressure is 200 pounds per square inch.

12. What is *superheated* steam? How is it produced?

13. What is a *Corliss* engine? How does it differ from other steam engines?

14. What are the uses of explosives? Explosives contain much chemical energy. Do you think this energy is harnessed when explosives are used?

15. *Hydraulic rams* use water power to pump water. Find out how they work.

16. Obtain a large sheet of paper. In the upper left corner draw a small "sun" with energy radiating from it. In the lower right corner draw a wheel and label it "Man's Work." Then complete your diagram by showing the different paths by which energy from the sun can reach the wheel and turn it. Give your completed diagram a suitable title.

17. A rotating lawn sprinkler is a kind of water turbine. Explain why it turns when water flows through it.

18. How does an automobile muffler make the exhaust so much less noisy?

19. How are the cranks and crank shaft arranged in *radial* airplane engines like the one in Figure 482?

20. Why does dust of some kinds explode when ignited? Compare the conditions with those in an automobile cylinder.

Fig. 496. This man may well be proud, because his prize corn has won for him the title of "World's Corn King" for three years in succession at the International Hay and Grain Show at Chicago. In this unit you will learn something of the ways in which such fine plants are produced and how man may change both plants and animals to bring out the characteristics most useful to him. (Acme photo)

UNIT TEN

UNIT 10

HOW DO WE IMPROVE PLANTS AND ANIMALS?

INTRODUCTORY EXERCISES

1. In what ways do you look like your father? Your mother?

2. In what ways are you different in appearance from your brother or your sister?

3. If you were a farmer and were trying to improve your crops and your livestock, in what ways would you try to improve each of the following: corn, wheat, chickens, dairy cattle, beef cattle, hogs?

*4. Name several ways in which plants reproduce.

*5. What is pollination? How may it be brought about?

*6. How is an egg fertilized? Why is fertilization important?

7. When someone says, "John inherited his father's nose," what does he mean?

8. Why are "pure-bred" animals much higher priced than ordinary animals?

9. In what ways do cultivated roses, apples, grapes, and cherries differ from the wild kinds?

10. How is it possible to grow many different kinds of apples on the same tree?

11. Name as many ways as you can of improving plants and animals.

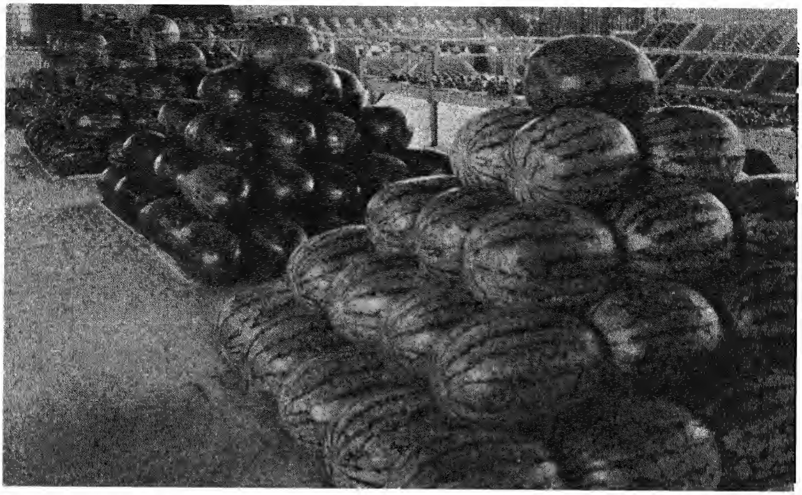


FIG. 497. Just one of these huge watermelons would be enough for a large family picnic. (J. C. Allen-Century photo)

LOOKING AHEAD TO UNIT 10

HAVE YOU ever attended a state or county fair? If not, try to do so sometime. But do not spend all of your time watching the races or attending the shows of the carnival. Go to the livestock exhibit and see the fine horses, cows, pigs, sheep, chickens, and turkeys that the farmers have brought to exhibit at the fair. Watch the judges examine the different animals for prize winners. Notice what characteristics they look for. Listen to what they are saying about the animals they are judging.

When you have finished with the livestock, go to the agricultural exhibits. Look at the huge ears of corn, the heads of golden wheat, and the other grains. Let your eyes linger on luscious apples, grapes, peaches, and pears. See pumpkins and watermelons so large that you can hardly lift one of them. Everywhere you look, you will see the finest products of nature, because these exhibits are the results of the best efforts of man to grow animals and plants for food.

It is hard to realize that these wonderful fruits and

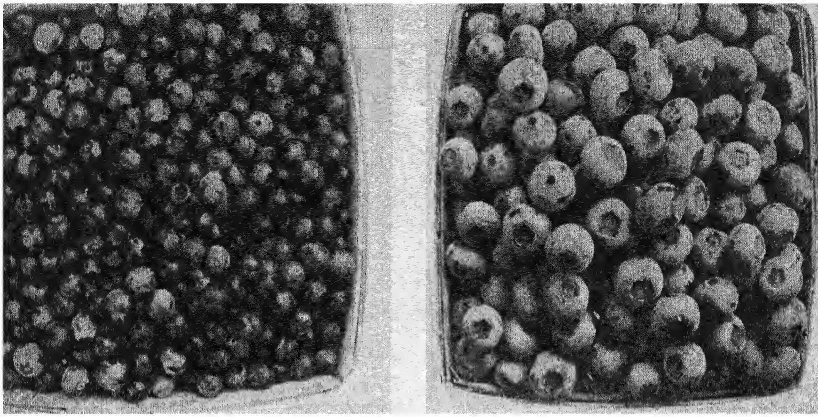


FIG. 498. After much experimental work man has developed a large, juicy blueberry, shown at the right, from the small, wild one shown at the left. (U.S. Department of Agriculture photo)

vegetables have been developed from wild ancestors. But such is the case. Perhaps you have eaten wild grapes, crab apples, strawberries, or plums. Some of them are delicious. But most of them are not nearly so good as the kinds we grow on our farms and buy in the markets. Yet these wild plants are the ancestors from which our fine domesticated plants have come. Our domesticated animals were developed from wild ancestors, too. Figure 499 shows a modern hog and its wild ancestor. They hardly look like the same kind of animal.

Perhaps you are wondering how living things can be made to change so greatly. Nature will of course bring about many changes in living things. In Unit 3 you learned that every living thing must be so made that it can get from its surroundings the things it needs to keep alive. When the environment of a plant or an animal changes, the plant or animal may change in such way or ways that it can stay alive in its new surroundings.

But the kinds of changes that man wants to bring about in living things are not always those changes that adapt the plant or animal to its environment. When we speak of improving animals, we mean improving them for our

FIG. 506. Although these cocker-spaniel puppies are offspring of the same parents, they show wide variations in the markings of their coats. (Photo by Dr. Duerer from *Dog World*, Chicago)

not look exactly like you. If the heredity for a certain trait is mixed, one child may inherit the recessive trait and another the dominant trait. When you think of how this applies to every trait you inherit, you can see why there are great differences among children of the same family. If two parents had several hundred children, you would find that traits would or would not appear according to the same pattern that Mendel found with plants. With only two or three children in a family, however, it is impossible to tell why certain traits are present or absent or to predict what will happen in the next generation.

Do you see, now, that there are differences among living things of the same species because of the fact that the higher plants and animals have two parents and that the offspring inherit traits from both parents? No two human beings are exactly alike; neither are any two plants exactly alike. The differences in living things of the same species are known as *variations*. Let us see what variations we find in one species of corn. If you should pick at random 100 ears of Golden-Glow corn and count the number of rows of kernels in each ear, you would find that they

would vary. In some ears you would find eight rows and in others as many as twenty rows. The average is usually about sixteen to eighteen rows. There are very few ears with only eight rows, and very few with twenty rows.

If you will look around you, you will see that there are the same kinds of variations in other living things. Only a few people are very tall, and only a few are very short. In a litter of pups you will find many different kinds of markings on the coats. The fact that variation does occur is of great importance to the plant- and animal-breeder. It makes possible the improvement of a given kind of plant or animal. You will learn more about this in the next problem.

Occasionally something happens that cannot be explained by what Mendel discovered about the way traits are inherited. A new and unexpected trait will suddenly appear in a plant or an animal. It never appeared in other plants or animals of the same species. Sometimes these strange variations are only freaks. They are not passed on to the next generation. Others are passed on; that is, the plant or animal breeds true so far as this trait is concerned.

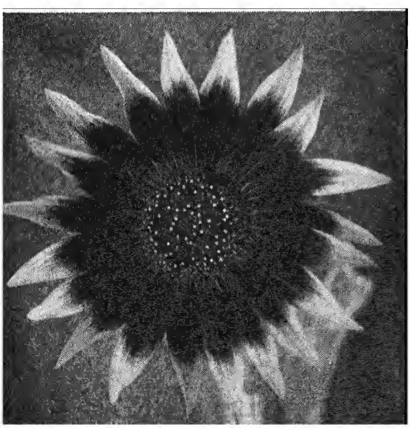


FIG. 507. A red sunflower bred from the mutation of the common sunflower found by Mrs. Cockerell beside a road in Colorado (Courtesy Prof. T. D. A. Cockerell)

Many examples of these unexpected changes in the structure of a living thing are known. In 1791 Seth Wright, a

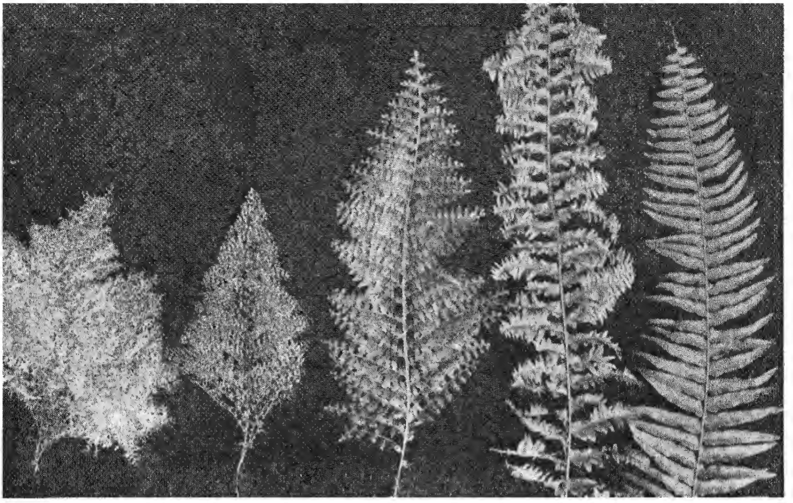


FIG. 508. At the right is the normal type of leaf of the Boston fern. The other four types have originated as mutations. (Brooklyn Botanic Garden photo)

Massachusetts farmer, discovered that one of his lambs had short, crooked legs. This lamb could not jump fences as well as the other lambs. So, when it grew up, Wright decided to cross this sheep (a ram) with another sheep in the flock. He did so, and he found that some of the offspring were like their father: They had short, crooked legs. He cross-bred those sheep and finally developed a new variety of sheep that would breed true for short crooked legs.

A new trait that breeds true is called a *mutation*. Many of the varieties of plants and animals that we have today have been developed as a result of mutations. For example, in 1910 there appeared in Colorado a sunflower with red flowers. Seeds from this plant were grown, and the following generations of plants also had some red flowers (Figure 507). In 1770 a hornless calf was born in Paraguay. Many of the hornless varieties of cattle that we have today are descendants of this one calf. Tailless dogs and cats, albino rats, and seedless oranges are other examples

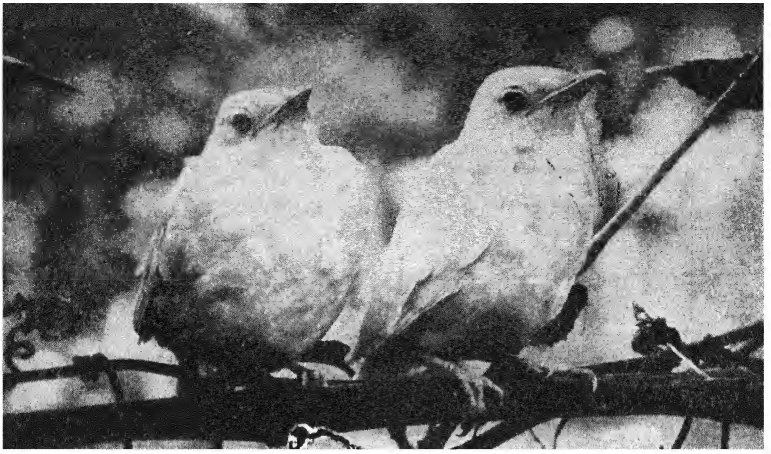


FIG. 509. A pair of white or *albino* robins. *Albinism* starts as a mutation and is inherited as a recessive trait. (Kobel photo)

of traits that first appeared as mutations. Just how mutations are brought about no one knows.

In the two examples you just read, man happened to be around to provide conditions that would allow the mutation to be reproduced. Of course, there are many mutations that man never notices. If these happen to be changes that help the living thing to get along better in its surroundings, the changes are likely to be continued in following generations. When this happens, a new species of living things may be established. However, many mutations that occur are not helpful to the living thing; in fact, they may be a disadvantage. When this is true, the living thing may die without producing offspring.

Self-Testing Exercises

1. Explain why children may differ from either or both parents in some trait.
2. Explain why children may be like one parent in one trait and like the other parent in a different trait.
3. What is meant by the term "variation"? Why do variations occur?
4. What is a mutation? Give two examples.

Problems to Solve

1. Collect leaves from different plants of the same species. Can you find any leaves that are exactly alike? In what ways are they different?

2. Find out from your parents whether or not your grandparents had some unusual characteristics. Do you find any of these traits in your parents? In yourself?

3. Why do the discoveries of Mendel not explain mutations?

4. Read about Gregor Mendel and report on his work.

5. Find out how individual variation in human beings has been applied in identifying criminals.

6. Find other examples of mutation.

7. Sometimes a characteristic skips a generation and then reappears. How could this be explained?

WHAT DOES A LIVING THING INHERIT FROM ITS PARENTS? Many people have wrong ideas about what they inherit from parents. We can inherit all kinds of physical traits such as you have been reading about. We also inherit something of our ability to learn. This is the result of the kind of brain that we inherit. But a person may inherit an excellent brain and, because of laziness or lack of opportunity, may fail to develop this brain. He will, therefore, be unable to use his excellent brain as well as some other person uses an ordinary brain that he has worked hard to develop. The ability to use your brain efficiently is not all inheritance; it is partly what you do with your inheritance.

You have perhaps heard also of children inheriting the ability of their father and mother to speak languages or to play the piano. This is another false notion. A person does not inherit the ability to speak French, German, or some other language. He inherits a certain kind of brain that enables him to learn easily. This kind of brain can be used for other kinds of learning as well. What usually

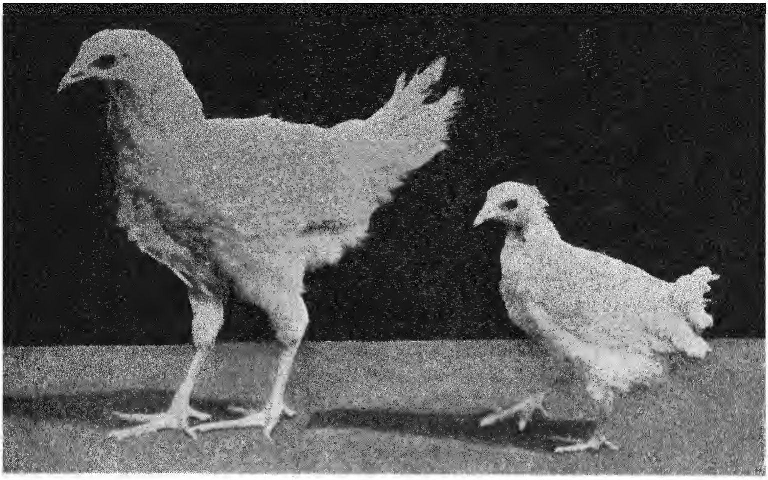


FIG. 510. These two chickens are the same age, and they began life with the same inheritance, but they grew up on different diets. The effect of an improper diet is seen in the poor development of the chicken at the right. (National Dairy Council photo)

happens is that the child gets interested in some skill or accomplishment that his parents have, and because of this interest he works hard to acquire this skill for himself. It is impossible for skills acquired by parents during their lifetime to be transmitted to their children.

You and other living things inherit certain characteristics of structure from your parents. You may inherit a strong body and an excellent brain. A plant may inherit the ability to grow an excellent root system. Your inheritance and that of the plant are the natural equipment that each of you has. You must remember, however, that inheritance alone does not account for the success of the living thing in life. A baby may inherit a strong body, but this body may not be developed because of lack of food or care. A plant may be weak and small because of lack of proper growing conditions. When you consider the condition of a plant or an animal, you always have to take into account the kind of environment it has. This environment may be the reason for its success or failure.

FIG. 511. These young people are making the most of their inherited traits by learning how to live healthfully. (Acme photo)

You may believe that you are fairly intelligent. If you happen to have inherited a good brain, you are fortunate. Because you have a good brain, you may think that you are superior to those who are not so intelligent. You may decide that you are so smart that it is a waste of time to study. This, however, is a mistake. You have to learn how to use your brain. A fine, delicate instrument is no better than a crude, clumsy one if the operator does not have the skill to operate it. The more you learn, the better you will be able to use your brain.

In your class there may be pupils doing better work than you do, even though you are sure they do not have as good a brain as yours. These pupils may not be so smart as you are, but they know how to use the brains they have. Curiously enough, it is frequently not the people with the best brains who have the most important positions in the world. Such positions are often held by people of average intelligence. You may wonder why this is true. The answer is that many highly intelligent people have never used their brains to the greatest advantage. They have acquired a "get-by" attitude, or they have become lazy. Sooner or later these habits of idleness catch up with

such people, and they are pushed aside by individuals who have really learned to use their brains to the limit of their capacity.

The same mistake is often made by people who inherit strong bodies. They never learn to take care of themselves. They eat the wrong things, fail to take exercise, and do not get proper rest and sleep. While they are young, there is apparently no ill effect. But when they begin to get old, they have to pay for this failure to take care of themselves.

Some people believe that a disease such as tuberculosis is inherited. You have probably heard that certain diseases *run* in certain families. We do not, however, inherit tuberculosis or other diseases. A person may inherit poorly developed or weak lung tissues. This may make him more susceptible, that is, less able to resist the disease. If other members of the family have the disease, the children may take it from them. It may appear as if the disease is inherited, but that is not really true. If the children are properly cared for, they will not necessarily become ill from the disease.

Inheritance, then, is only part of the story. It merely determines what kind of body and brain you start out with. The kind of life you live may make it possible or impossible for your inheritance to be of the greatest benefit to you.

Self-Testing Exercises

1. What does a living thing inherit from its parents?
2. What traits are commonly said to be inherited that are really not inherited?
3. In what way does the environment affect our inheritance?
4. Why is a good brain not the only thing necessary for being successful?

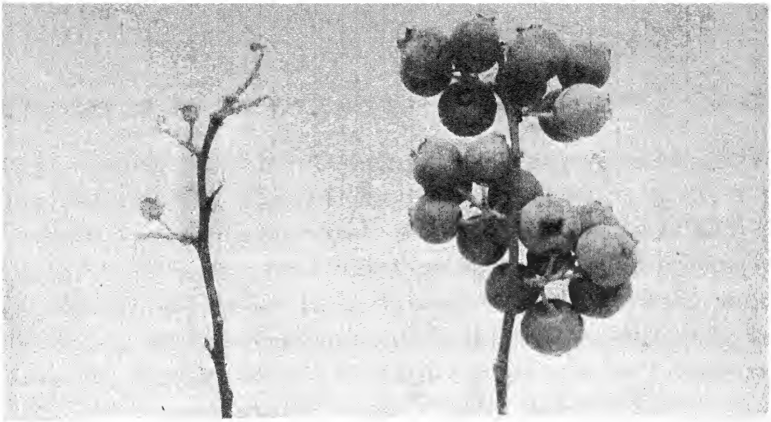


FIG. 512. These twigs bearing such different-sized blueberries grew on the same bush. The variation in size of the berries resulted from using pollen from the same bush on the flowers of the twig on the left and pollen from another bush on those of the right-hand twig. (U.S. Department of Agriculture photo)

Problems to Solve

1. Do you know any parents of your classmates who are talented in music, art, cooking, and athletics? Are the children talented in the same way?

2. Why do you suppose that people years ago believed that tuberculosis was inherited from the parent or parents?

3. In the newspapers there are frequent reports about the Dionne quintuplets. If you can find such reports, read to see what variations there are in these five children.

4. Do people inherit habits? Give reasons for your answer.

Problem 2: HOW ARE DESIRABLE KINDS OF PLANTS PRODUCED?

PROBABLY the biggest job that man has is to see that there is food enough for everyone. You have read of the great famines of the past, where millions of people died because of lack of food. Revolutions, wars, and business depressions sometimes result in famine for many people even today, but this is not because we cannot produce enough food for everyone. Wars, revolutions, and depressions happen because men and women are still very

selfish or very foolish, or both, and do not know how to get along with their neighbors throughout the world.

The story of how man has learned to grow plants that give him more and better food, that can survive under poor growing conditions, and that can resist the attack of plant diseases is one of the most fascinating in modern science. You can learn a little of the story here, but only a little.

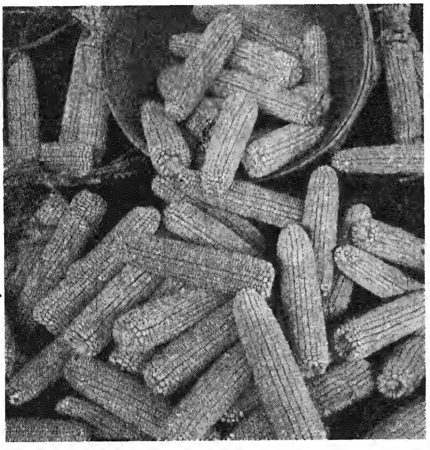


FIG. 513. If next year's seed is selected from fine ears of corn like these, the crop will doubtless be improved. (J. C. Allen-Century photo)

HOW CAN WE IMPROVE PLANTS BY SELECTION? Let us suppose that you are a farmer and that you want to increase the yield of your corn crop. How would you go about it? To begin finding the answer to this question, suppose we take a walk through a corn-field and see what kinds of variations we can find. First of all, we find sickly or weak stalks that bear poorly developed ears. We find some plants that have long stalks, but very few ears, and plants that need too long a growing season for the development of the ears. We see, also, plants that are too short and that mature their ears too early. When we examine the ears themselves, we find some that are not well filled at the ends and some that have crooked rows and irregular-shaped kernels. From what you have learned about heredity, you know that offspring are likely to resemble

their parents. None of the characteristics mentioned so far is desirable.

Now let us look for plants with better qualities. We will look for strong plants that show no signs of disease. We will look for ears with straight rows of kernels and well filled out with kernels at the butt and the tip. We will examine the kernels to find those with broad tips, because such kernels are much richer in food and yield more corn to the cob. Our investigations show us that there are great variations in the quality of the corn in our field.

In getting seed for next year's crop, you can see what would happen if we merely saved for seed several bushels taken hit-or-miss from all over the field. The seed would come from poor plants and from good plants. We would get about the same kind of crop that we got the year before. No improvement would result because we would have made no improvement in our seed. What else can we do? We can select the best ears from the strongest plants. While we are husking the corn, we can throw these ears aside. Then we will have the best ears only, and if we plant the seed from these ears, our chances of getting a good crop next year will be much better.

We can also improve our chances for a good crop by testing the germination qualities of our corn. Two ears of corn may look equally good. The kernels may also look about the same. You may think that one ear is as good as another. But this may not be the case. The kernels from one ear may germinate well, while those from the other may not. So we decide to test the germination qualities of our seed corn.

The simplest method of testing seed corn is called the *rag-doll* test. First, sheeting is torn into strips eight inches wide and from three to five feet long. The cloth is divided

into squares by drawing a line through the middle of the strip and then drawing cross lines about every three inches. Each of these squares is numbered, and the cloth is then spread out. Each of the ears of corn to be tested is now numbered, and ten kernels from different parts of each ear are placed in each square. In this way from thirty to fifty ears may be tested at one time.

FIG. 514. Rag-dolls ready for the test (U. S. Department of Agriculture photo)

The cloth is now rolled up carefully, tied loosely with a string, and placed in water for from eight to twelve hours. It is then put into a box for about five days, by which time the seeds will have germinated. The roll is now opened, and the seeds are examined. Unless all ten kernels have strongly germinated, the ear is discarded and not used for seed. If we use this method of testing our seed, we can be certain that the seed we plant will germinate. Therefore we will be sure of a better yield from the seed we plant. If we do this year after year, we will slowly increase the quality of our seed corn.

There is, however, a still more reliable method of getting better seed. If we test our seed, we know whether or not it will germinate, but we do not know what kinds of ears will be produced. Corn is pollinated by the wind. The pollen from all the corn, both poor and good, is flying around in the air. We have no way of knowing whether pollen from good plants or poor plants has pollinated the ears. The ears may be good on this year's plant, but we

cannot be sure that the plants grown from the seed will be good. So we decide to find out which of the ears will produce the best corn.

We take the seed from ear No. 1 and plant it in a row that we call Row 1. We do the same for the other ears that we have selected. In the fall we measure the corn we get from each row. We may find that some rows produce from two to four times as much as other rows. Naturally, we select our seed for the next year from the best rows. Of course, this will not give us enough corn for all of our planting next year. We can, however, plant this selected seed in a plot by itself and then select the best ears from this plot for the next year's planting. In this way we can in a few years build up a high quality of seed corn and thus a better yield of corn.

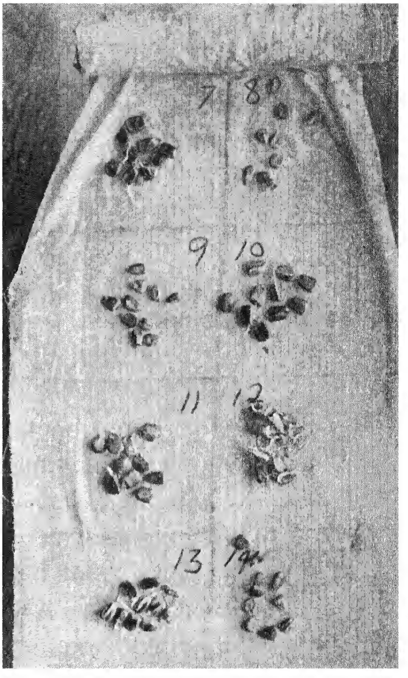


FIG. 515. The results of the rag-doll test show that only one of the ears tested is a good one to use for seed. (U. S. Department of Agriculture photo)

Improvement by this method, of course, has its limits. We cannot go on forever producing larger and larger ears, because a plant has only certain possibilities of development. Beyond that it is impossible to go. These methods of improving plants are called *selection*. In the first method the best ears of corn were selected and shelled, and the seed was all planted together. This is called *mass selection*. In the second method a record was kept of the *progeny*

FIG. 516. The central row of corn is a variety very susceptible to destruction by the chinch bug. Crossing this kind of corn with a resistant variety produced hybrid plants, seen in the other two rows, that are much less injured by the bug. (U. S. D. A. photo)

(offspring) of each ear; that is, the seed of each ear was kept separate, and a record was made of the amount of corn produced by the seed. This is sometimes called the *progeny-performance* method. As you can see, the progeny-performance method of breeding is more difficult to carry on than the mass-selection method, but the results are much better.

A good example to show what can be done to improve plants by selection is an experiment that was carried on with flax. Flax is often attacked by a fungus that causes a disease known as *flax wilt*. When the flax is harvested, this fungus remains in the soil and attacks young plants the following year. As a result, flax cannot be grown in the same land year after year. This situation became very serious in the Northwest; so scientists began to look for some way to remedy it.

Professor H. L. Bolley of the No. Dakota Agricultural Experiment Station noticed that some plants in a field of flax were apparently not attacked by this disease. He selected some of these plants and planted seeds from them, using the progeny-performance method. After several

years of selecting plants that were resistant to the disease, he finally produced a strain of plants that was highly resistant. As a result of this selection it is possible to grow flax year after year on the same ground, even when the fungus that causes flax to wilt is present in the soil.

Self-Testing Exercises

1. Why is the method of selecting corn by progeny performance more likely to improve the crop than selection by the mass method?
2. Why is it wise to make a germination test? What does such a test tell you about your seed?

Problems to Solve

1. Plan an experiment to improve the seed in some flower or some garden vegetable.
2. Interview your local seed dealer. Find out where he gets his seed and how the seed is selected.

HOW ARE NEW VARIETIES OF PLANTS PRODUCED? One of the most remarkable stories of how man can produce a new kind of plant is found in the development of Marquis wheat, a kind that is now widely grown in the northern part of the United States and in Canada. It took ten years to do the experimental work and to place this wheat on the market for farmers. The story of its development will help show you how new varieties of plants can be produced.

Canadian farmers usually planted a variety of wheat known as Red Fife. This was a good wheat with a good yield. Unfortunately, however, it needed a fairly long growing season to mature. As a result, every few years the crop would be destroyed by early frosts—frosts that came before the wheat was ripe. What the farmers needed was a wheat with a high yield that would ripen earlier.

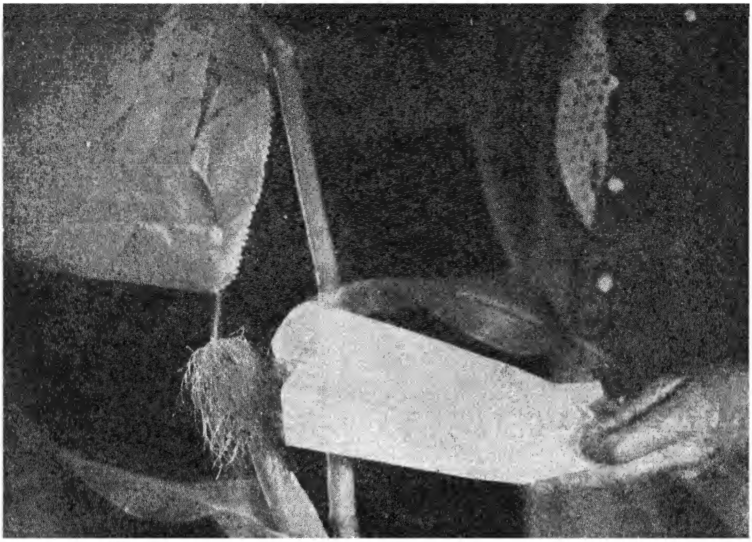


FIG. 517. When corn plants are pollinated by hand, pollen from the tassel of the male parent is collected in a paper bag. The ear shoot of the female plant has been covered to keep out stray pollen; and after the desired pollen is poured on to the silk of the female parent, the bag is at once replaced. (Associated Seed Growers, Inc. photo)

But no such wheat could be found; so scientists began to look around. In India they found a hard, Red-Calcutta wheat that ripened early, but unfortunately it yielded very little wheat, and what it yielded was of poor quality. If they could just combine the high yield of the Red Fife with the early maturity of the Red Calcutta, the problem would be solved.

The work started in 1902. First of all, the scientists had to be sure that cross-pollination would take place between the Red-Fife wheat and the Calcutta wheat. To do this, they removed the stamens from a flower of one kind of wheat plant. This made certain that self-pollination could not take place. This plant then became the female plant. The flower was shielded from other pollen by covering it with a paper bag. The ripe stamens were then removed from the other variety of plant and were crushed over

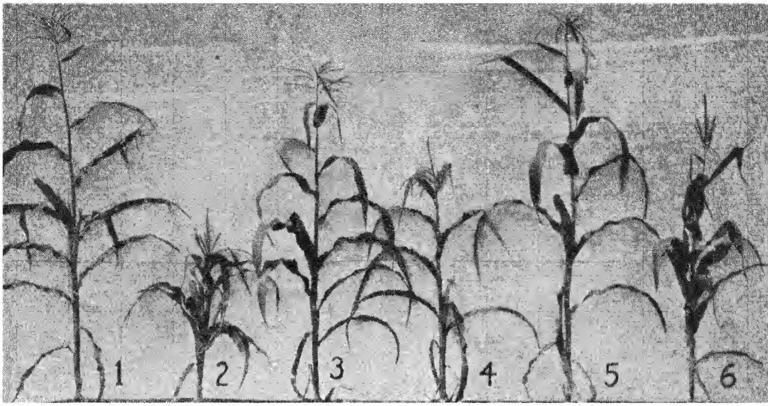


FIG. 518. How corn is improved. Plant 1 is a pure-bred variety shown for comparison. Plants 2 and 4 were cross-pollinated, and from their seed grew plant 3. Plants 4 and 6 were cross-pollinated, and from their seed grew plant 5. Notice that plants 3 and 5 are both taller than the parent plants 2, 4, and 6. (U. S. D. A. photo)

the pistil of the female plant. The pistil was again covered with the bag. In this way the pistil of the Red-Fife plant could be pollinated with the pollen from a Red-Calcutta plant, or the reverse.

The wheat seeds produced from this cross were, of course, hybrids. They were planted. Some of the seeds grew into plants that matured early and produced a fair yield of wheat. Seed from these plants was then planted. Year after year the process of selection and cross-breeding went on. It was a long process. Four years after the beginning of the experiment the scientists had less than one bushel of the kind of wheat they wanted. But this wheat had both of the desired qualities: It matured early, and it had a good yield.

A few years later enough seed had been produced to distribute some to Canadian farmers. It was an immediate success. By 1913, after eleven years of work, 100,000 bushels of the new Marquis wheat were grown and distributed to farmers of the United States and Canada. By the year 1918, over 300,000,000 bushels of this wheat were produced.

Fig. 519. Pollinating hundreds of tomato plants by hand is a huge task, when each one requires such close attention.

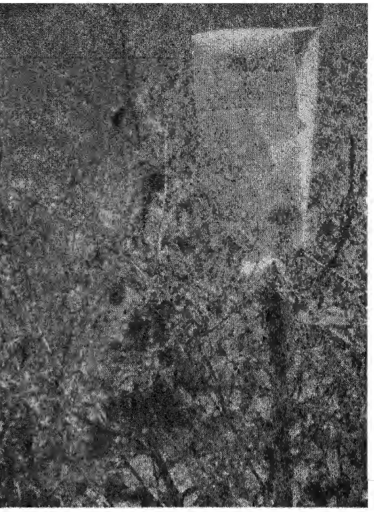


Fig. 520. The flowering branch of a beet plant is bagged to keep out stray pollen. (Associated Seed Growers, Inc., photos)

In this example of the production of Marquis wheat, you see what the process of cross-breeding is. It is a process of combining the good qualities of different varieties of plants into one plant that will breed true. Years are required to produce a fine strain of plant, because only by raising and selecting plants over a period of years can the undesirable characteristics be eliminated so that the plants will breed true. Many desirable varieties of plants have been produced by this method.

Perhaps the best-known plant-breeder was Luther Burbank, who died only a few years ago. Among the plants he developed are the white blackberry, the Lawton berry, a walnut tree that grows very rapidly, and the Elephant-Heart plum. The development of the white blackberry is an interesting story. Burbank heard of a wild blackberry that had berries of a muddy-brown color. This gave him the idea that he might be able to produce a white blackberry. The berries of the wild plant were of no value because they were too small and tasteless. To

develop a white blackberry that would be of value, Burbank had to keep three goals in mind: (1) He had to get a whiter berry, (2) he had to get a larger berry, and (3) he had to get a berry of better quality.

First, he looked around for a domesticated berry that was large and of good quality. He found this in the Lawton blackberry. So he cross-bred the wild blackberry with the Lawton blackberry. The seeds that developed produced plants with black berries. We would expect this because the black color was dominant over the lighter color, and the offspring were hybrids. However, seeds from these berries were planted, and some of the next generation of plants produced yellowish-white berries. The best of these were selected and grown, and some of the next generation of plants produced berries so white and transparent that the seeds in them could be plainly seen. The best of these were selected and planted, and this same process was carried on for many generations. Finally Burbank secured plants that would breed true.

You might think from this illustration that the production of new kinds of plants is very simple and easy to carry on. As a matter of fact, it is most difficult and expensive. In one year Burbank discarded 65,000 blackberry plants that did not have the desirable characteristics. Successful plant breeding is only possible when it is carried on on a very wide scale. Thousands of plants must be grown, most of which are thrown away. Each year only a very few are selected to serve as breeding stock for the next generation. Many years are required to carry on the experiments, and sometimes millions of plants must be raised before a successful cross is produced. In a way such breeding is not the creation of anything new. The breeder starts with plants that have the desired

characteristics. His job is to get all of the desired characteristics in one plant. The result, though, is a new variety of plant. It is a plant that differs from the original plants from which it was produced.

Self-Testing Exercises

1. How does the scientist make sure that self-pollination does not take place in the plants he cross-breeds?
2. Why is cross-breeding likely to result in plants with new characteristics?

Problems to Solve

1. Does a scientist actually create some new kind of plant? Give reasons for your answer.
2. Show how Mendel's experiments with plants explain what happened in Burbank's experiment with the white blackberry.
3. Read about Luther Burbank in reference books and learn about some of the other new plants he produced.

HOW ARE DESIRABLE PLANTS PRODUCED FROM PARTS OF PLANTS? You already know that many plants are grown from *cuttings*. To do this a plant that bears excellent fruit or beautiful flowers is selected, and cuttings are made from either the roots or the stems. One end of the cutting is placed in sand, soil, or water. Roots develop from the cutting, and it grows into a new plant. When this method of starting new plants is used, we do not need to bother about the hidden heredity of the plant. The cutting will develop into a plant with the same characteristics as the plant from which it was cut. Cuttings, as you can see, are valuable in growing hybrid plants. If we plant the seeds of a hybrid plant, we may or may not get a plant with the desired characteristics. We can be sure, however, that a cutting will grow into a plant with the same characteristics. Red raspberries, plums, and blackberries are often grown from cuttings.

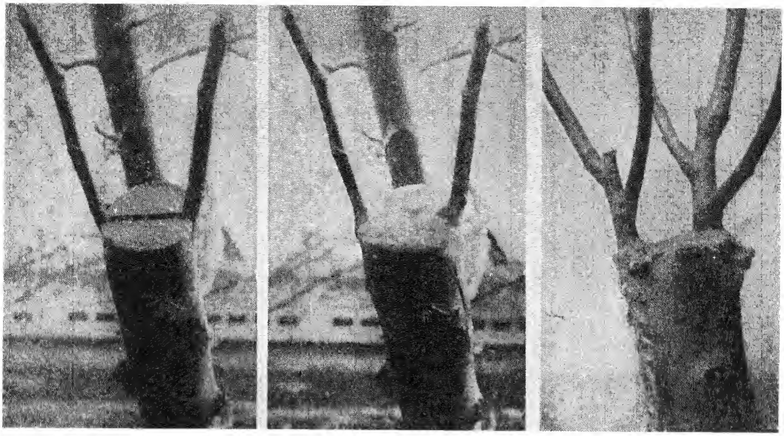


FIG. 521. In making a cleft graft the stock is split, the scions are cut and inserted so that the cambium layers are in contact (left), and wax is applied (center). The picture at the right shows the scions well established and growing. (International Harvester photos)

Another method of growing plants with certain desirable characteristics is *grafting.* This is of great value in growing fruit trees. If an apple seed is planted, the tree that develops may not produce the kind of apple we want because of the mixed inheritance of the seed. If a Jonathan or any other variety of apple is wanted, the usual method is to plant apple seeds of any kind. The plants that develop are allowed to grow until they become fairly good-sized. Then the upper part of the plant is cut off, and twigs from a Jonathan tree are grafted on to the plant.

You remember that a twig increases in diameter by the division of the cells in the cambium layer of the stem. In grafting, the cambium layer of the twig to be grafted (the *scion*) is brought into contact with the cambium layer of the twig upon which the graft is made (the *stock*). The graft is then covered with wax to hold it together and to protect it. Curiously enough, the top of the tree above the graft will bear fruit of the Jonathan variety regardless of the variety of the stock upon which it is grafted. Trees have been grown in which scions from many different kinds of apples have been grafted on one root system. In

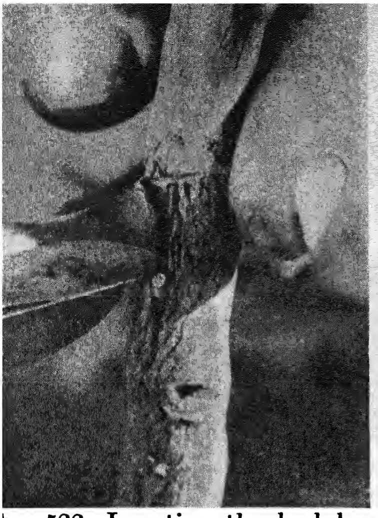


FIG. 522. Inserting the bud beneath the bark of the stock in the budding of an orange tree

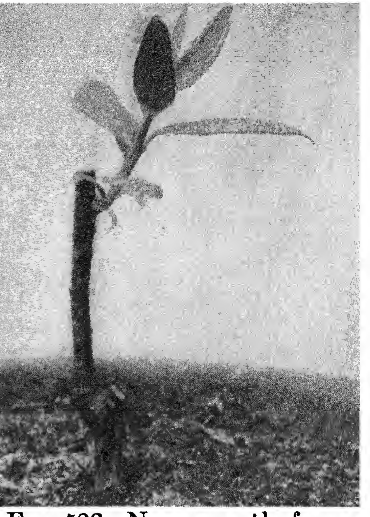


FIG. 523. New growth from an inserted blueberry bud (U. S. Dept. of Agriculture photo)

this case many kinds of apples are grown on a single tree.

A slightly different method of growing a desirable plant is by *budding*. In budding, a bud with a small piece of bark attached is removed from a good kind of tree. This bud and bark are then placed under flaps of bark on a small tree grown from seed. When the bud begins to grow, the main stem of the tree is cut off just above the bud. The branch from this transplanted bud then develops into the whole top of the tree. Peaches, cherries, and grapes are usually grown by this method. The seedless orange first appeared as a mutation in Brazil. It is now largely reproduced by budding seedless-orange scions on trees grown from ordinary orange seeds. Most of the seedless oranges that you eat are grown on trees propagated in this way from the original seedless-orange tree.

Oranges are a good example of the value of grafting. Wild oranges have such excellent root systems that the plants can grow in colder climates than the climates in which our domesticated varieties can grow. The fruit of the wild orange, however, is not so large, sweet, and juicy

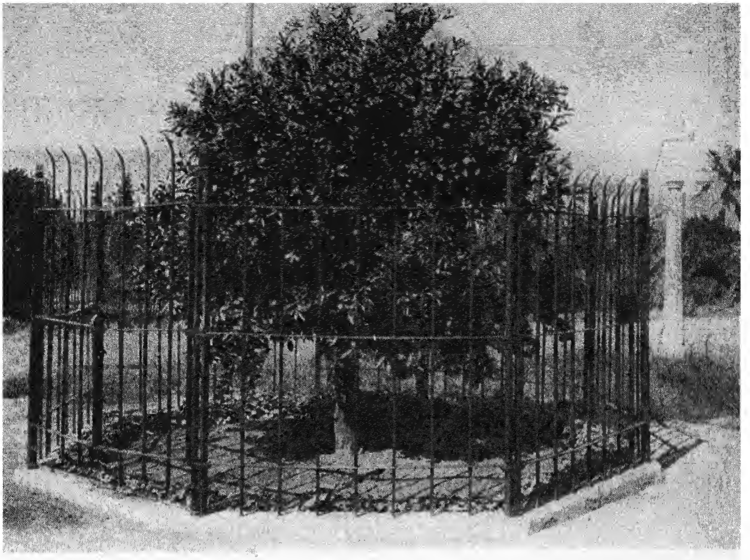


FIG. 524. This carefully protected tree is one of the first two seedless orange trees sent to California. Enough bud wood has come from this small tree for acres of seedless-orange groves, but it is still producing good fruit. (Calif. Fruit Growers Exchange photo)

as the fruit of our cultivated kinds. To secure the advantage of the root system of the wild orange, it is only necessary to grow a seedling of the wild orange and then graft on it a scion from a domesticated variety. The roots will be those of the wild orange, and the fruit will be that of the cultivated orange. Here, again, we do not need to be concerned with hidden heredity.

Self-Testing Exercises

1. What is the difference between a cutting and a graft?
2. How does budding differ from grafting?
3. Why are grafting and budding used by fruit growers?

Problems to Solve

1. Why must the nurseryman be careful to have the cambium layer of the scion and stock in contact with each other?

2. A farmer has two kinds of apple trees. He discovers that there is a market for one kind of apple but not for the other. What might he do?

FIG. 525. Compare the scrub cow on the left with the pure-bred one on the right. (U. S. Bureau of Animal Industry photo)

Problem 3:

HOW ARE DESIRABLE KINDS OF ANIMALS PRODUCED?

WHAT IS A PEDIGREED ANIMAL? Those of you who live or have lived on farms know that high prices are sometimes paid for male cattle, horses and hogs. A single animal may sell for thousands of dollars. Of course, no animal is worth this sum of money merely as food or for work. But the animal is valuable because it can be used to produce other fine animals like itself. Such animals are said to be *pure-bred*, or *pedigreed.* You hear the same terms applied to dogs, cats, chickens, and other domesticated animals. What do these terms mean? Do you know why pure-bred animals cost so much money?

Before we answer the question, "Why do pure-breds command high prices?" let us see what a pure-bred animal is. A pure-bred animal is one whose ancestry is known for several generations. The system of keeping records of animals, known as the *pedigree system,* started in England about 200 years ago. Under this system each animal's name is recorded, and a number is assigned to the animal. The name and number of the *sire* (father) and of the *dam* (mother) are also recorded. Today, a farmer buying a

pure-bred animal can often trace the ancestry of the animal for a hundred years or more.

The pedigree record also contains information about certain characteristics of the animal and its ancestors. For example, a record of a trotting horse gives also the speed of the horse, that is, its record in traveling a certain distance. A record of a dairy cow gives its production of milk and of butter fat.

What the farmer or horse-breeder wants to know is whether or not a given animal can pass its desirable characteristics on to its offspring. This information can be obtained from the register. For example, all the offspring of a given *stallion* (male horse) with a certain speed record are registered. The pedigree shows its matings with various mares of different strains and the speed record of its offspring. The records may show that the offspring of this stallion do not seem to be as good animals as the stallion. The stallion is therefore no longer used as a breeding animal. Another stallion does pass his fine characteristics on to his offspring; therefore, he is kept as a breeding animal. In this way there is a process of selection going on for each generation. The best animals, that is, those that pass on their own fine qualities to their

FIG. 526. The use of *grading* has improved the wool production of these sheep. The sheep at the right, which was sired by a pure-bred ram, has a much better fleece than its scrub mother.

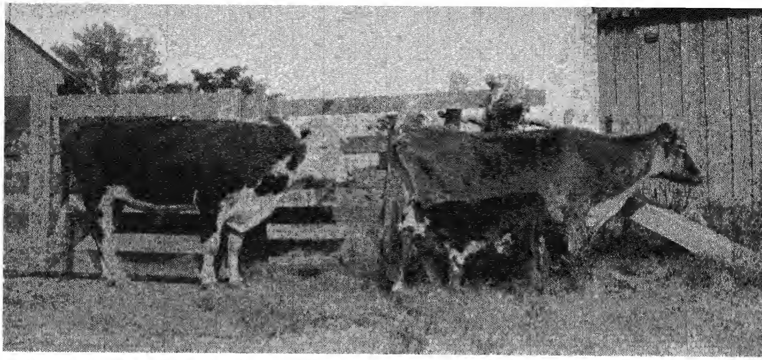


FIG. 527. The calf was the offspring of a cross between a pure-bred Hereford sire and a scrub dam. Notice that the calf shows the characteristic Hereford markings of its sire. (U. S. Bureau Animal Industry photo)

offspring, are selected for breeding purposes. Do you see why pure-bred animals are worth so much money?

In actual practice there are different methods of raising better animals. In pure-breeding only registered males and females are used. This system secures the best results, but since registered animals cost much money, it is an expensive method. It is used mainly by animal-breeders who are most interested in producing animals that they can sell for breeding purposes.

HOW ARE ANIMALS IMPROVED BY GRADING? The most common method of securing better animals is called *grading*. In this method the sire is a pure-bred animal, while the dam is not. Let us see how this method of breeding is used on dairy farms. Curiously enough, experiments have shown that the amount of milk a cow will give depends more on the father of the cow than upon the mother. An experiment carried on in Iowa a few years ago shows how important it is to use a pure-bred bull, whose ability to pass on the trait of a high yield in milk has been proven. In this experiment cows were bought in Arkansas. Nothing was known about their ancestry. They were just the common run of cows. A record was kept of the amount of milk they produced and the pounds of butter fat contained

in this milk. Then the cows were mated to pure-bred bulls, and a record was kept of the milk production of the daughters. These daughters were mated to pure-bred bulls, and a record was kept of the milk production of the granddaughters. The results (Table 4) show that the

TABLE 4. COMPARISON OF DAM, DAUGHTER, AND GRANDDAUGHTER RECORDS

Cows	Milk pounds	Butter-fat pounds	Increase	
			Milk per cent	Butter-fat per cent
Dams	3660	171	...	...
Daughters	5998	261	64	52
Granddaughters	8401	358	130	109

granddaughters produced more than twice as much milk and butter fat as the original cows.

You must not think, however, that just because a bull is pure-bred, it is necessarily a good bull. Some pure-bred bulls do not pass on the desired characteristic of high milk production. The only way to discover whether a bull will pass on this ability is to keep a record of the production of milk of his daughters. A farmer may buy a young bull whose pedigree seems to indicate that its daughters will be good milk producers. As the daughters grow up and begin to produce milk, a record of their milk production is kept. If this production is high, then the bull is kept for breeding purposes. If the record is not good, he is sold or sent to the butcher.

Table 4 shows how a herd of dairy cows may be improved. The best daughters are selected and mated with a pure-bred bull whose ability to pass on the trait of high milk production has been tested. Through selection, year after year, the quality of the herd is improved. In the

same way the ability of hens to lay eggs can be improved, as shown in Table 5. From these examples you can see that grading is a very effective way of improving the livestock on a farm. It is less expensive than raising registered animals, and the results are almost as good.

TABLE 5. IMPROVEMENT OF EGG PRODUCTION BY GRADING*

Breed	Number of Eggs Laid in First Year			
	Mongrels	First-Generation Grades	Second-Generation Grades	Third-Generation Grades
White Leghorn	75	166	197	198
Plymouth Rock	105	135	166	207

*Data from Lippincott in Kansas Agr. Exp. Sta. Bul. 223.

Still a third method of obtaining improved varieties of animals is used by men who are trying to obtain new breeds of animals. The method used is cross-breeding. It is the same type of method employed in plant breeding. This is, of course, a long and expensive process and is carried on only by experienced breeders with plenty of time and money.

Self-Testing Exercises

1. What is a "pure-bred" animal?
2. What is the method of selecting "pure-bred" sires for breeding purposes?
3. What is the difference between pure-breeding, grading, and cross-breeding?

Problems to Solve

1. Visit a dairy farm. Find out what method the farmer uses to improve his herd.
2. Look up the pedigrees of noted race horses. Make a list of famous horses that have descended from some noted ancestor.

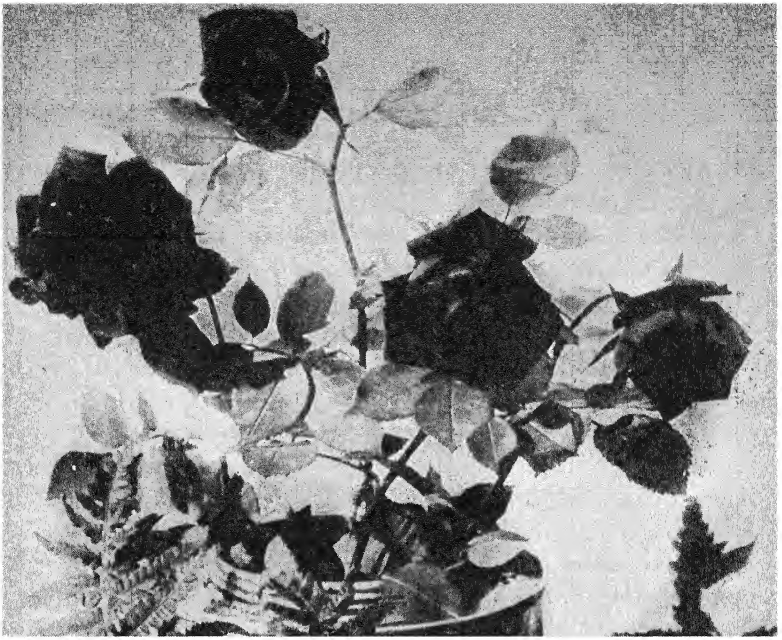


FIG. 528. Have you ever seen a black rose? Not many people have, for these rare flowers were produced in Germany only after many years of experimental work. (Acme photo)

LOOKING BACK AT UNIT 10

1. Write a two-page summary of the most important ideas that you have gained from studying this unit.

2. Make a list of the questions that you have had that have been answered in this unit.

3. Show that you know the meanings of the following terms:

heredity	*sire*	*dam*	*variation*
cross-breeding	*trait*	*inheritance*	*recessive trait*
breed true	*blend*	*dominant trait*	*mutation*
mass selection	*hybrid*	*progeny performance*	*grafting*
scion	*stock*	*pure-bred animal*	*grading*

ADDITIONAL EXERCISES

1. Get some seed catalogs and find new varieties of flowers that have been developed.

2. Find out from your parents what new vegetables and fruits have been developed or improved since they were young.

3. Why can a plant-breeder make progress more easily than an animal-breeder?

4. Refer to yearbooks of the Department of Agriculture. Report on the experiments in plant- and animal-breeding that are presented in these yearbooks.

5. Find out the contributions made by Darwin, Davenport, DeVries, Galton, Lamarck, Mendel, and Weismann to the science of heredity.

6. Find out how seedless grapefruit were developed.

7. Obtain Farmers Bulletin No. 1567, U. S. Department of Agriculture, on budding and grafting. Find out the details of how to graft and then try it.

8. Make some cuttings of evergreen trees. Cut a slip from the parent plant with a sharp knife held at an angle. Plant the end of the twig in a good soil and sand mixture. Keep the cutting under good growing conditions and see if it will produce roots.

9. Make a report on the origin of each of five pure breeds of some domesticated animal. Your report should include a discussion of the particular characteristics, both physical and otherwise, that distinguish each breed.

10. Read *Hunger Fighters* by Paul DeKruif, and find out how experiments have been carried on to produce better wheat and corn.

11. Collect pictures for a bulletin-board exhibit of different breeds of cattle, sheep, hogs, chickens, and horses.

12. Figuring three generations per century, calculate how many ancestors you must have had (*a*) in the year 1800, (*b*) the year 1000, (*c*) the year 800 B.C.

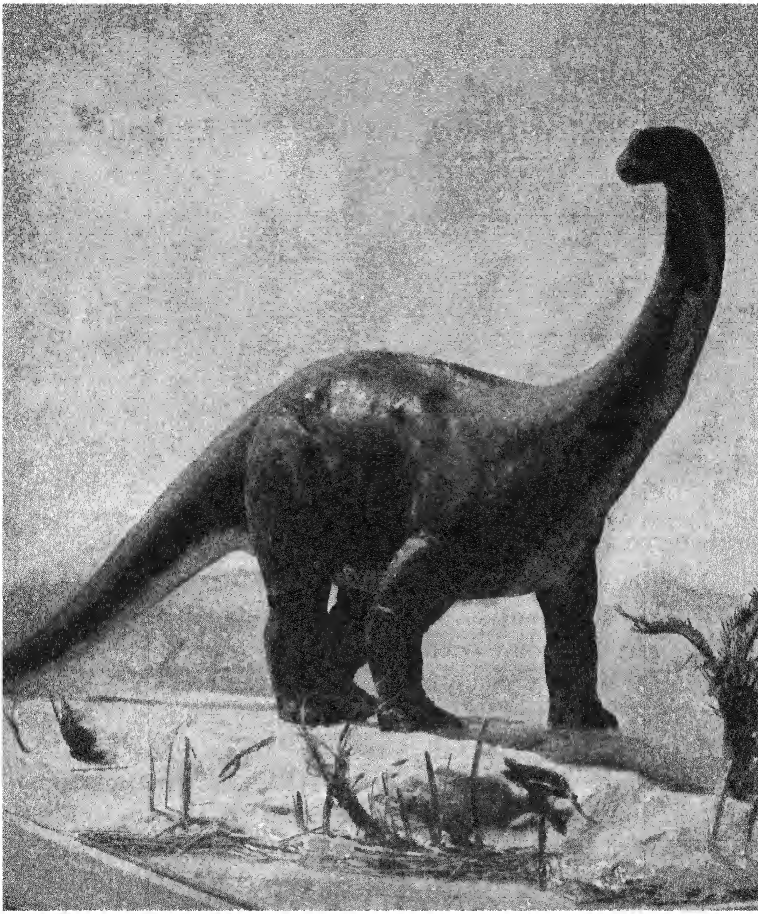


FIG. 529. Millions of years ago Brontosaurus, the giant thunder lizard, roamed the world with earth-shaking footsteps. But his kind did not survive, and today we see him in museums only, reconstructed from the bones found beneath layers of deposited rock and soil. In this unit you will read something about the changes that have taken place in the earth and its inhabitants, and how man can read the history of these changes from rocks and the remains of the earlier living things. (Courtesy of Sinclair Refining Company)

UNIT ELEVEN

UNIT 11

HOW HAVE LIVING THINGS DEVELOPED ON THE EARTH?

INTRODUCTORY EXERCISES

1. How old do scientists think the oldest known rocks are? How do scientists estimate the age of these rocks?

*2. Why are some oceans and lakes salty?

*3. How does erosion change mountains?

*4. Tell in your own words how rocks are formed from sand and clay.

*5. What are igneous rocks? What are metamorphic rocks? How is each kind formed?

6. What are fossils? What facts have scientists learned by studying fossils?

*7. What are *radioactive* elements? Name some of these elements.

8. Millions of years ago many strange animals, known as *dinosaurs*, lived on the earth. What reasons could you give to explain why dinosaurs have disappeared from the earth?

9. How do new kinds of animals get started upon the earth?

10. Why do we find kangaroos only in Australia and elephants only in Africa and Asia?

11. Make a list of the great groups of plants and another list of groups of animals. Begin with the simplest kinds.

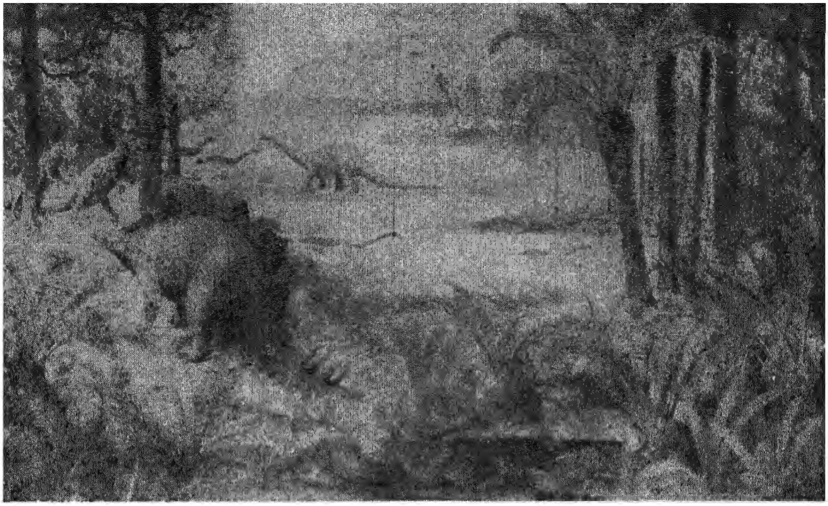


FIG. 530. When these strange dinosaurs dominated the earth, they were surrounded by a rich vegetation of fern-like cycads and some other cone-bearing trees. (Courtesy of Royal Ontario Museum)

LOOKING AHEAD TO UNIT 11

WHAT DOES the title of this unit mean to you? What are some of the things you think you will learn in this unit? If you could go back about 200 million years, you would find plants and animals very different from those that are living now. You would see many ferns and fern-like plants. The "petrified forests" of our western states (Figure 531), with their peculiar cone-bearing trees, would be alive and covering the hillsides. In other places you would see countless numbers of palm-like trees, known as cycads, and other curious plants. Groups of strange reptiles, known as *dinosaurs*, would dominate the land, air, and water. There would be no human beings, because they did not appear until millions of years later.

If you could go back still further into the earth's history, say 325 million years, the plants and animals would be even different from the ones that have just been described. In those days strange kinds of fish with heavy, bony armor lived in the seas, and you would find some of the

Fig. 531. "Petrified" trunks are the only remnants of the forests of early cone-bearing trees that covered these hillsides millions of years ago. (H. H. Darton and U. S. Geological Survey photo)

earliest kinds of amphibians. These amphibians were large salamander-like animals nearly three feet in length. You would see forests of ferns and strange relatives of the ferns eighty feet tall. But there would be no plants with seeds or flowers. These living things were far more ancient than the ones you first read about. Figure 562 shows some of them. Compare these living things with those in Figure 530 and with the plants and animals of today to get an even better idea of how vastly different living things were at different times in the earth's history.

But how do we know about these plants and animals of millions of years ago? For us to know about them, there must be some sort of record of the plants and animals of the past. We cannot just imagine what living things were like and let it go at that. What kinds of records do you think the living things of the past have left?

In your history classes you have found that many kinds of records have been left by people to tell us how they lived in the past, such as old letters, diaries, and early laws. Earlier records were carved in clay and stone and painted on the walls of caves. Bones of animals and of men, remains of dwellings, and crude tools and household utensils help tell the story of the still more distant past.

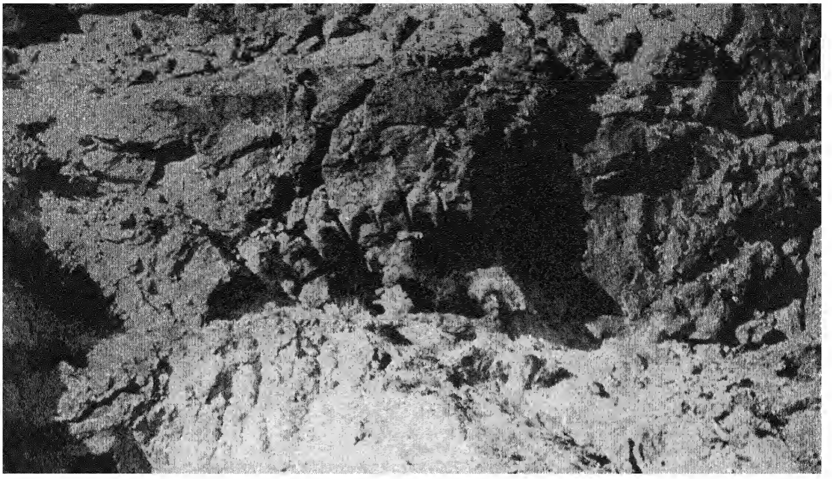


FIG. 532. When the geologist finds a deposit such as these dinosaur bones, he is uncovering another clue to the history of the earth. (Dr. Barnum Brown, American Museum photo)

But what about the story of life before man appeared upon the earth and began to make records? You know that plants and animals cannot leave the kinds of records that people have left. However, they have left certain records that can be read by those who know how to read them. Curiously enough, the geologist gets his information about the living things of the past directly from the things that were once alive. He does not have to depend upon what someone else has said. He studies the actual remains of the dead plants and animals in the rocks. These remains, as you know, are called *fossils*, and they show the structure of the living things that left them.

However, we want to know more than just the structure of living things of the past. We want to know how plants and animals developed; that is, we want to know how living things have changed since the first living things appeared on the earth. Geologists know that different kinds of fossils are found in different layers of rock. If we can discover the ages of these different layers, then we can tell about the age of the fossils.

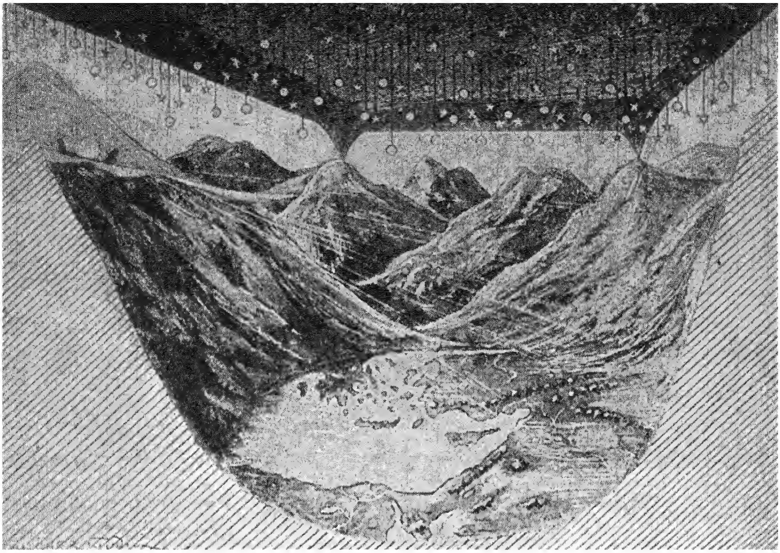


FIG. 533. Our ideas of the earth and its history have changed greatly since the time when the ancient Egyptians believed the universe looked like this. (Yerkes Observatory photo)

Problem 1:

HOW DO GEOLOGISTS DISCOVER THE HISTORY OF THE EARTH?

HOW DO THE CHANGES IN THE EARTH TODAY HELP US TO LEARN WHAT HAPPENED IN THE PAST? People have had many curious beliefs about the earth. For example, some of the ancient people believed that fossils were strange rocks formed under the influence of the stars. Only within the last 150 years have men found out what really happened to the earth in the past and what kinds of plants and animals have lived on it.

One way of studying the past is to study what is happening now. Geological processes are going on today just as they were in the past. The surface of the earth changes slowly, but even within the memory of people alive today some changes have taken place. So, if scientists study the changes that are going on now, they can find clues to explain what has happened in the past.

About 2000 years ago the Romans built a temple on the

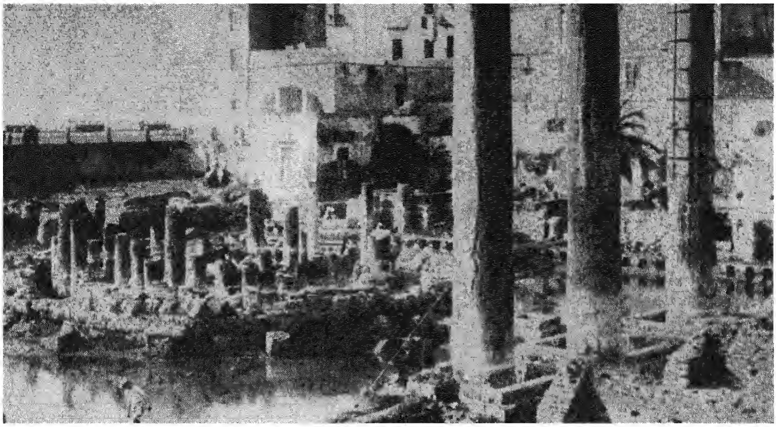


FIG. 534. Holes bored by sea animals in the columns of this ancient Roman Temple give evidence that the building was under water for many years because of the sinking of the coast line. (Acme photo)

seashore near Naples. Through hundreds of years the land sank gradually until the water stood twenty-one feet high on the stone columns of the buildings. Small, shelled sea animals bored holes in the columns and lived in them. Later, the land rose above the water, and the temple was rediscovered about 200 years ago. In its columns were holes made by the sea animals during the centuries that the land had been under water. Today the coast is sinking, and the temple is slowly going under the water again.

Land is rising and sinking in other parts of the world, too. Over 100 years ago a fisherman along the northern coast of Sweden cut marks in the rock at the water's edge. Today these marks are a number of feet above water. Geologists tell us that the northern coast of Sweden has risen about seven feet in the last 175 years and that parts of our western coast are slowly rising today.

You must not get the idea that most of the land over the earth is rising. Some of it is rising, some of it is stationary, and some of it is sinking. The paved streets of a certain town in southern Sweden were on dry land many years ago; now they are under the sea. Much of the

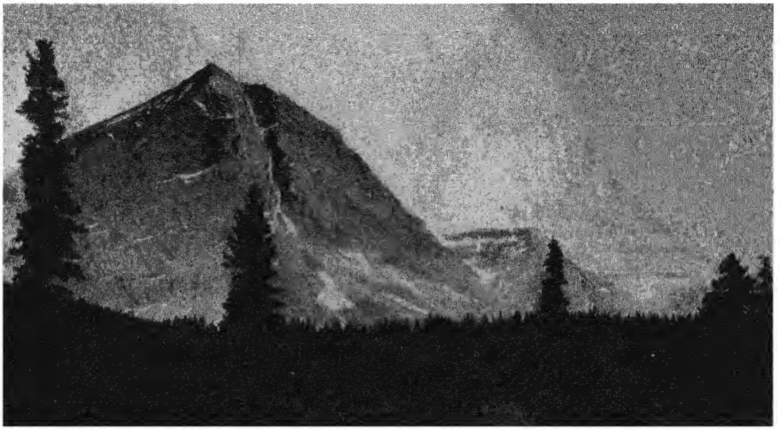


FIG. 535. Geologists know that lofty Mt. Robson in Canada was once under water, because they have found the remains of sea animals in its layers of sedimentary rock. (Acme photo)

eastern coast of the United States is slowly sinking. The islands in New York Bay are the tops of hills that are still above water. These hills were once part of the land. Parts of the New England coast are gradually sinking, and the Chesapeake Bay is really a "drowned river valley." The river systems of this region were formed when the land was well above sea level. Later the land sank, and water pushed up into this valley, making the bay as it is now. Of course these changes take place very slowly. Parts of England are sinking, but scientists estimate that, at its present rate, it will take about 40,000 years for it to sink beneath the sea.

Since you have learned that even today land is still sinking in some places and rising in others, it is not so hard to believe that this has been going on all during the millions of years of the earth's history. Even though the movement is very slow, great changes can take place in the long periods of geological time. A rise of one foot a century would lift land almost two miles in a million years. Do you see why the remains of sea animals can be found in rocks on the tops of hills and mountains?

From your previous study of science you know that land is being eroded in some places and built up in other places. Deep river gorges are being cut, and new rocks are being formed slowly as material is deposited. When geologists find old gorges that are now filled up, the eroded remains of ancient mountains, or other formations, they can tell what has happened in the past. Since we know that these happenings are taking place today, it is not difficult to link them up with past happenings. Using the present to help tell what happened in the past was one of the ways by which scientists began to learn the history of the earth.

FIG. 536. The ripple marks on the beach of an ancient sea (Chicago Mus. photo)

James Hutton, Scotch physician and farmer, was one of the first people to use this method. This Scotch farmer liked to walk along the sandy beach near his farm. On still days he saw the beautiful ripple marks the waves made in the sand, and on stormy days he saw the waves wearing the rock cliffs away. Also, he found ripple marks in the hardened sandstone along the shore. He reasoned that these marks in the sandstone must have been made by waves on a sandy beach countless years before. Sand was washed over these marks, and the coast gradually sank as more sand was deposited. Then the sand hardened into sandstone, and in this way the ripple marks were preserved. Then, reasoned Hutton, the beach must have been raised above the sea, and the waves must have cut into the sandstone to expose the ripple marks. He was reading the history of this beach from what was happening in the present.

Self-Testing Exercises

1. Explain how scientists know that land is rising in some places and sinking in others.

2. Tell in your own words how a knowledge of what is happening to the earth now helps us find out what has happened in the past.

Problems to Solve

1. Why do you suppose many people think that the earth is not changing today?

2. In some good reference book find more about the work of James Hutton.

WHAT DO LAYERS OF ROCK TELL ABOUT THE EARTH'S HISTORY? When rock layers are exposed, they are the pages from which geologists read a great deal of the earth's history. The materials of which the rocks are made tell something of how they were formed. You recall that sedimentary rocks are formed by eroded material that settles to the bottom of seas or streams or that is deposited in layers by wind. If the rocks are sandstone, the geologist knows they were made from tiny pieces of another kind of rock (quartz) that might have been deposited by wind or swiftly running water. If the rocks are shale, he knows they were made from tiny particles of mud that settled in still water. And if the rock is limestone, the scientist knows that it was formed at the bottom of a body of water and that it was made mainly of material from the shells and skeletons of sea animals.

The way layers of rock lie in relation to each other also helps geologists read the history of the earth. For example, look at Figure 537. In this figure you see that the upper layers are horizontal. What does this tell a geologist? In the first place, he knows that layers of sediment which change into rock are always deposited in

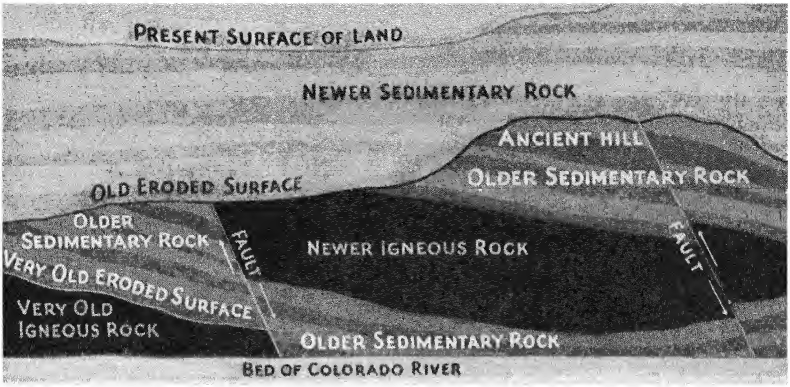


FIG. 537. This diagram shows what happens to layers of rock where a fault occurs. The places labeled "Old Eroded Surface" are the unconformities.

horizontal layers. So any tilted layers must have been originally in a horizontal position. How, then, did they come to be tipped? One end was raised, and the other end was lowered; or great pressure may have been exerted from each side, causing the layer to fold. You can show how this last could happen by pushing on the ends of a writing tablet or other thin pad of paper. Figures 537 and 538 show that these layers must have been raised above the sea and that erosion has taken place. This is not quite so easy to see. How can a scientist tell this?

Geologists know that the rocks were lifted and eroded because the layers of horizontal rock on top of the tilted layers are not the same layers that are found in other places. They are layers that were formed much later in geological history. So the geologists reason that the rocks must have been tilted and lifted above the surface of the sea at some time in the earth's history. Later these tilted layers must have sunk below the sea again. How do they know this? They know it because new layers of rock have been deposited on top of the tilted rock. These places between layers of older rocks and layers of newer rocks are called *unconformities*. At these places the rocks do not conform, or agree. They show that changes have taken

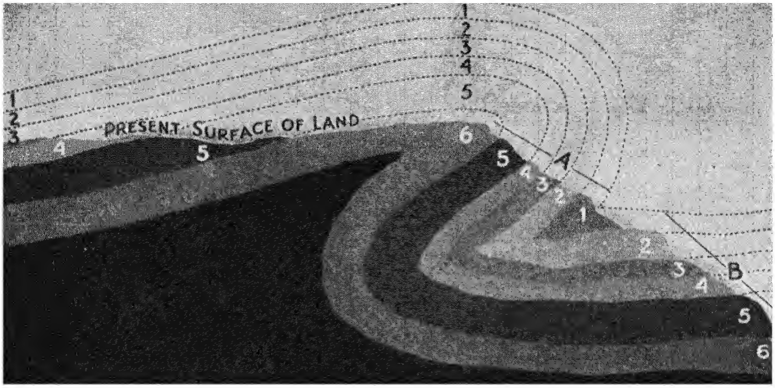


Fig. 538. If you follow the numbers showing the layers, you can see how rocks can fold and how the folding may pile older rock on top of newer rock.

place between the time the old rocks were formed and the time the newer rocks were laid down. Thus they separate the geological history of that region into divisions.

When sedimentary rock is formed, the oldest layers are usually at the bottom, and the youngest are at the top. This, too, helps us find out about the past. But the geologist must be very careful about saying that the youngest rocks are at the top, for, as the earth's surface changes, rock layers may be folded over, and the old layers will appear at the top (Figure 538).

Often great cracks are found in rocks, as Figure 537 shows. These cracks where the rocks have broken and slid past each other are called *faults*. When geologists find these cracks, they know that some tremendous force broke the rocks and moved them along past each other. Sometimes a block between two faults has been pushed up above the rocks on either side, or it may have fallen down between them. Such happenings help to show us the changes that have taken place in the past.

In Grand Teton National Park, Wyoming, and in many other places, there are peculiar banded rocks. The layers of these rocks are often found in wavy bands, which shows that they have been changed by great pres-

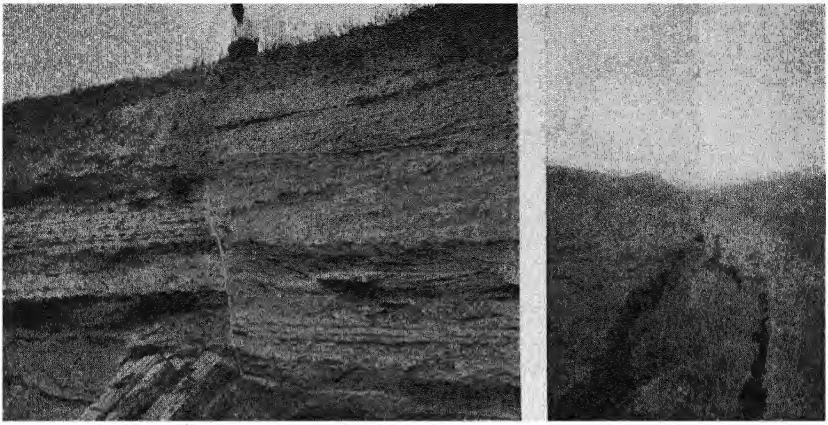


FIG. 539. The line of a fault may often be followed, on the surface of the earth, along great cracks that open up above the break in the rocks. (U. S. Geological Survey photos)

sure. Rocks that have been changed by pressure and heat are known as *metamorphic* rocks. They were once other kinds of rock, but changes inside the earth have changed them. In some places the rock is found not to be in layers at all. It appears to have been melted at some time and then hardened as it cooled again. This kind of rock, you will remember, is igneous, or "fire-formed," rock. Sometimes igneous rock is found squeezed in between layers of sedimentary rock. This tells us that the sedimentary rock must have formed first and that the melted rock was later forced in between its layers. Other masses of igneous material tell geologists by their peculiar arrangement that they were once parts of ancient volcanoes.

From this brief story of the ways in which geologists read the history of the earth, you can see that the positions of rock layers and the order in which the layers are found can be used to tell what must have happened.

Self-Testing Exercises

1. How is sandstone formed? Shale? Limestone?

2. The youngest layers of sedimentary rock are usually at the top. Use a pad of colored construction paper or layers of clay to show how older layers may get on top of younger layers.

FIG. 540. Great collections of bones stored in museum workrooms must be studied and assembled before the scientist can tell us the story of animal life on the earth. (American Museum photo)

3. What happens to cause a fault in layers of rock?
4. State several important facts that can be learned about the earth's history by studying the layers of rock.

WHAT DO FOSSILS SHOW ABOUT THE PLANTS AND ANIMALS OF THE PAST? When you hold the fossil remains of some plant or animal, it is hard to believe that you are holding an object that may be millions of years old. The word *fossil* really means "something dug up," for ancient people found fossils by digging in the rocks.

Most of the fossils that are found are the hard parts of animal bodies, that is, the shells, bones, teeth, etc., or the hard parts of plant bodies. You can easily see why this is true. Most of the soft parts decay soon after the animal dies, and only the hard parts are preserved. For the entire body to be preserved, an animal must be covered soon after death with some kind of material that will keep the air away from it. Sedimentary materials, such as clay, sand, and lime-mud, are the usual materials that cover the bodies of dead animals and plants. That is why fossils are usually found only in sedimentary rocks.

However, other materials such as resin, volcanic ash, dust, ice, and tarry substances have often covered and preserved animal bodies.

The most valuable kind of fossil is the kind in which both the hard and the soft parts of the animal or plant are preserved. Over 100 years ago the remains of a mammoth (an ancestor of the elephant) were found in the ice in northern Siberia. It had been in "cold storage" since the last great Ice Age, thousands of years ago. Scientists believe that many of these animals are preserved in the glaciers of Siberia and Alaska. They make valuable finds for scientists, for their bodies are in almost perfect condition. Other quite perfectly preserved fossils are found in oil-saturated soils in Poland and in natural asphalt pits in California. Amber (the hardened resin of ancient cone-bearing trees) from the shores of the Baltic Sea often contains insect bodies that have been preserved for millions of years. However, such perfectly preserved fossils are scarce.

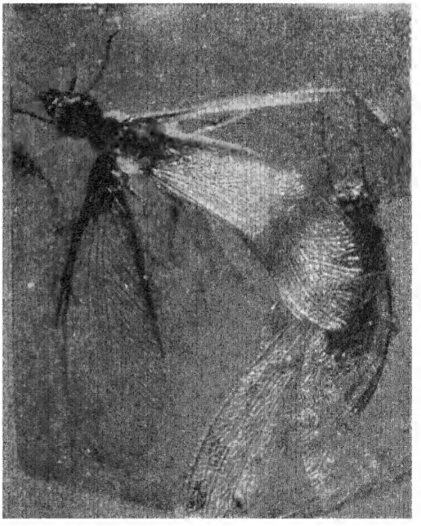


Fig. 541. An extinct species of termite preserved in amber (P. S. Tice photo of specimen from Dr. A. E. Emerson, University of Chicago)

Another type of fossil is the remains of a plant or animal whose body or body parts have been changed into stone. We say that it has *petrified*. Sometimes an animal or plant may become buried, and the soil around will harden. Then the body decays, leaving a mold that looks like the animal or

FIG. 542. The imprint of a fern leaf (Walker Museum, Univ. of Chicago photo)

FIG. 543. The footprints of a dinosaur that has long been extinct. (Chicago Museum photo)

plant. Later this mold fills with minerals that harden. When the rock is broken, we find a "mold-fossil" that looks like the living thing that made it.

Still another kind of fossil is known as an *imprint*. Figure 543 shows the print of a dinosaur's foot that was made in soft soil. Later this print was covered with more soil which finally hardened into stone. In Pennsylvania, Connecticut, and many other parts of the United States, particularly in the West and the Northwest, tracks of these animals are found in rocks. Prints of leaves, shells, and other objects are common. In coal mines fossil imprints of ferns and other kinds of plants are often found. Even the trails made by worms as they crawled along and the holes bored by them for homes have been found fossilized in rock.

Over 150 years ago an Englishman by the name of William Smith recognized the value of fossils in learning about the earth's history. He reasoned that fossils of a certain bed of rock show what was happening when the rock was being formed. Scientists have since learned that certain kinds of fossils appear in different groups

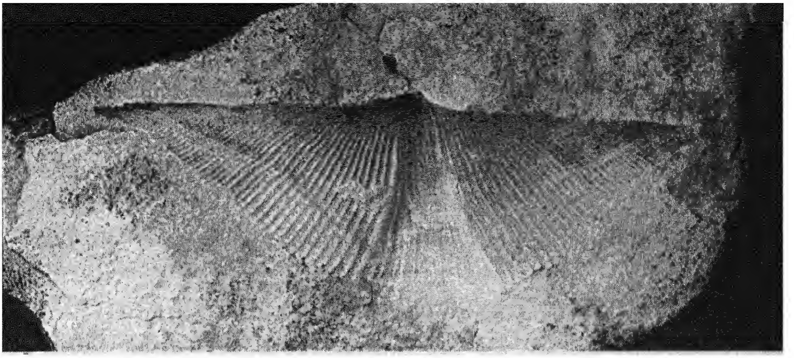


FIG. 544. The mold of a brachiopod (Walker Museum, University of Chicago photo)

of rocks. However, each different division of geologic time contains fossils that appear only in that division. For these reasons fossils enable geologists to separate the history of the earth into *periods*. That is how geologists can tell the approximate age of the rocks and fossils.

One of the most important things fossils show is what kinds of plants and animals lived in the past. In addition to this, they help us to know what the climate was like then and under what other kinds of conditions the plants and animals lived. For example, the fossil fern in Figure 542 lived in a warm climate and must have grown in or near a shallow, fresh marsh. Coral that is now fossilized could have lived only in warm, shallow seas, and the mammoth mentioned on page 621 must have lived during a cold age when there was much ice. Sedimentary rocks often contain fossil imprints of raindrops, ripple marks, and mud cracks. These, too, tell us of the conditions on the earth when the fossils were formed.

Self-Testing Exercises

1. Why are the soft parts of animal and plant bodies not often preserved?

2. Explain why fossils are found in sedimentary rocks and not in igneous rocks.

3. List three different ways in which fossils are formed. Explain each and give examples to illustrate it.

4. What do fossils tell about the past? Give illustrations to prove your points.

5. How do fossils help geologists tell the age of the rocks?

Problem to Solve

Read in some good reference book to find (*a*) how fossil exhibits are prepared for museums, and (*b*) what fossilized animal bodies have been found in asphalt pits.

HOW DO WE READ THE "GEOLOGIC TIME-TABLE"? People who have not studied geology often get the idea that the earth has always been much the same as it is now. However, from your study of the unit this far, you know that the earth is constantly changing. These changes go on so slowly that a person can observe only very slight changes in his whole lifetime. The average life span of man today is about sixty years. When you remember that the oldest known rocks are at least two billion years old, you can easily see why you can observe so little of what is really happening to the earth. Two billion years is time enough for a great deal to have taken place. What have been some of the outstanding events that have happened to the earth during all this time?

First of all, the geologists have found that the history of the earth can be divided into certain parts. The longest division in the earth's history is known as an *Era.* In the earth's past history there have been at least five important eras. These eras are shown in Table 6. One of the first questions that you will want to ask is, "How do geologists tell when one era has ended and another has begun?" Eras are represented by layers of rocks that are enough alike to separate them from other layers. Plant and animal fossils and other features make them alike. The ends of eras are marked by unconformities or breaks in the record that are great enough to be found all over the earth.

were deposited first, and the younger layers were deposited on top of them. When you read Table 6, you begin reading at the bottom and read upward. A section of the rock layers from which this table is made might be thought of as a column of rock with the oldest at the bottom and the youngest at the top. However, at no single place in the earth will the entire column be found, for some of it has been destroyed. Geologists have had to piece the column together by studying the best examples of rock from different places over the earth. So our time-table is an ideal one that has been put together from many pieces. At any single place in the earth you will find parts of this column, but not all of it.

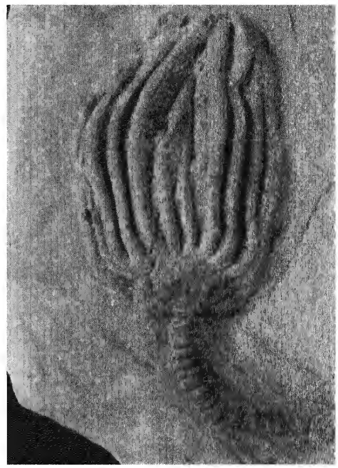


FIG. 546. In the latter part of the Paleozoic Era stalked crinoids were abundant. (Photo by Dr. Ralph Buchsbaum from his *Animals Without Backbones*)

You begin reading the table in the lower left-hand corner. The first column shows the eras. The next column shows the periods into which the eras are divided. The figures in the second column show the number of years (in thousands or millions) that have passed since each period began. The third column shows the most important changes that have happened to the earth, and the last column shows the changes that have taken place in plants and animals. Of course, you need not memorize the names of eras and periods or the events that have happened. The most important thing is for you to understand the story in general, that is, some of the great changes that have happened to the earth and plants and animals.

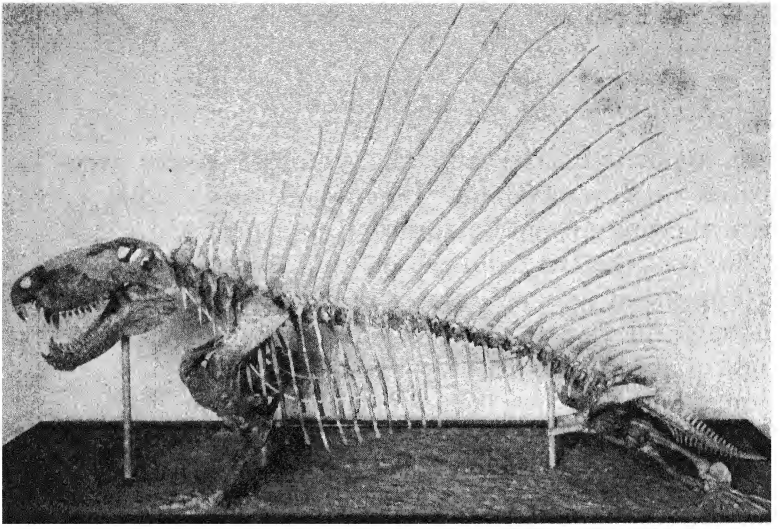


FIG. 547. By the end of the Permian Period reptiles had developed greatly, and such creatures as the fin-backed Dimetrodon were common. (United States National Museum photo)

Self-Testing Exercises

1. Make your own definition of *eras*. Of *periods*. Read the book again to see whether you are correct.

2. How do geologists tell where, in the rocks, the record of one era ends and another era begins?

3. What is believed to have happened to the earth between eras?

4. Why are geologic charts or "time-tables" read from the bottom upward?

5. To get the general plan of the earth's history in mind, you will find it worth while to study the geologic time-table in Table 6 with great care. Perhaps the best way to do your studying will be to make a copy of the time-table for yourself. Do this thoughtfully. Underneath it or on a separate sheet of paper write some of the questions about it that you would like to have answered.

Problem to Solve

Find in reference books other kinds of geologic time-tables. Compare them with Table 6. How are they alike? Do they disagree on any important points?

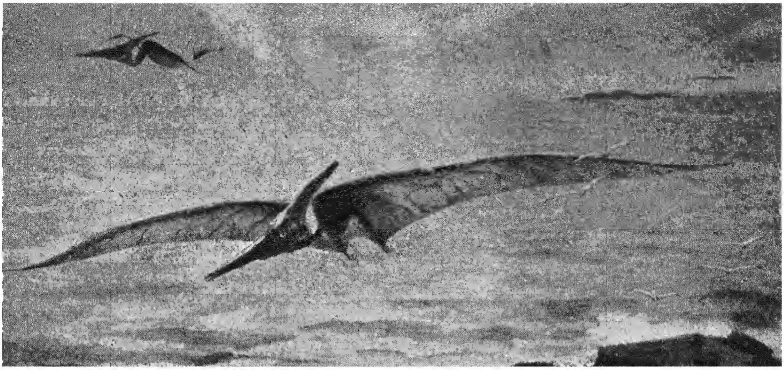


Fig. 548. Giant flying reptiles with a wing spread of nearly thirty feet and small toothed birds flew over the seas during the Cretaceous Period. (United States National Museum photo)

HOW DO GEOLOGISTS ESTIMATE THE AGE OF THE EARTH? Scientists have used about forty different methods in trying to estimate how old the earth really is. Of course, it is not possible to state the earth's age exactly. However, an interesting thing is that each of the forty methods indicates that the earth is very, very old; so old, in fact, that we can scarcely imagine it. Let us examine briefly a few of the best of these methods.

One method that has been used is based upon how fast the land is eroded in some places and how fast it builds up in other places. Scientists have estimated that all of the different layers of sedimentary rocks that have been deposited over the earth would form a layer between seventy and one hundred miles thick. They have also estimated that it takes about 880 years to form one foot of rock. Dividing the thickness of the rocks by the rate of formation gives the age of sedimentary rocks.

When material is deposited in one place, it must have been eroded from another place. So the rate of erosion is used with the rate of formation as a method of checking the age of the earth. The United States Geologic Survey has estimated that about 10,000 years are needed on an average for a layer of material one foot thick to be eroded

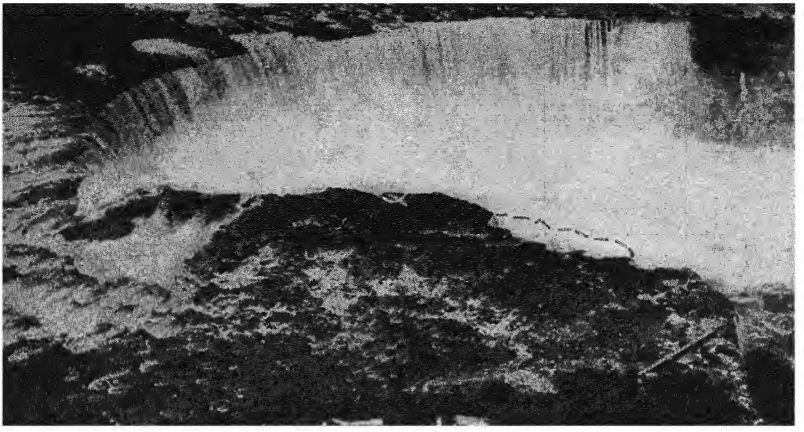


FIG. 549. The dotted line shows the brink of Niagara Falls before great masses of rock fell from the rim in 1934. By studying the rate at which the falls are wearing away, the age of the gorge can be estimated. (Acme photo)

from the surface of our country. You can readily see that it would take a very long time for much erosion to occur. However, the rate of erosion and deposition of materials during the ages seems to have been uncertain. It was probably much faster at some times than at others. So the best we can say about the age of the earth by using this method is that it is tremendously old.

However, geologists do believe that the rate of erosion is valuable in telling how long ago recent events have happened. For example, the Niagara River is wearing away the rock over which it falls at the rate of about 2.3 feet per year. To have formed the seven-mile gorge through which it now flows below the falls must have taken from 18,000 to 30,000 years. This figure also tells how long ago the last great Ice Age was, for these falls are believed to have formed when the glaciers melted away.

Another way of estimating the age of the earth is based upon the amount of salt in the ocean. All the water that enters the ocean contains some salt mixed with the other minerals it has dissolved. Scientists have estimated

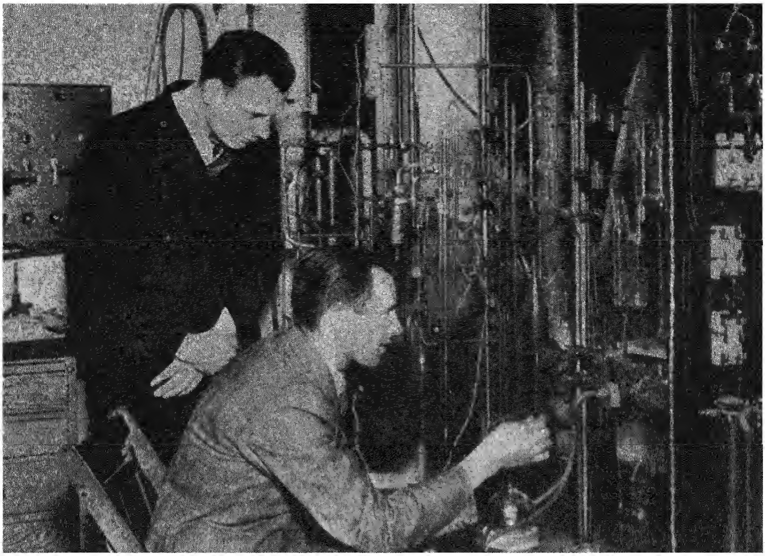


FIG. 550. These two scientists are using a very complicated piece of apparatus to determine the age of rocks by measuring the amount of helium present. (Science Service photo)

rather accurately that about 160 million tons of salt are added to the ocean each year in this way. They have also analyzed sea water and from this have calculated the total amount of salt in the oceans. Dividing the total amount in the oceans by the amount added each year gives a staggering figure for the age of the earth. We must be very careful to be scientifically accurate in our statements; so the best estimate we can make from this method is that the oceans themselves are tremendously old, certainly well over 100 million years.

The most accurate way of estimating the age of the oldest known rocks has only recently been discovered. This method is based on the changes that take place in igneous rocks. Certain elements, such as uranium, are constantly going through a series of changes, until finally helium (a gas) and lead are formed. These elements are called *radioactive* elements. The rate of these changes is

always the same; it is not influenced by outside conditions. Therefore, this is believed to be the most accurate method of estimating geologic time. A sample of rock containing uranium is found. The amount of unchanged uranium in it is compared with the amounts of helium and lead that are present. Then, by using a mathematical formula, the age of the rock can be estimated. The oldest known rock on the earth is a specimen that came from northwestern Russia. Its age is thought to be about 1,852,000,000 years. From the different methods used, the minimum time since the formation of the earth's crust must have been at least 2,000,000,000 years.

Self-Testing Exercises

1. Name three methods by which geologists estimate the age of the earth. Explain each method briefly.
2. Which of the above methods is believed to be the most accurate? Can you tell why?
3. How old do scientists believe the earth must be?

Problem to Solve

Write to the state geological survey at your state capital for information about the geology of your region. Tell them that you want to know about the kinds of rocks in your locality and how old they are. Study the material you receive to learn about the oldest and the youngest rocks in your locality. What are some of the great changes that have taken place?

Problem 2:
WHAT HAVE GEOLOGISTS LEARNED ABOUT THE LIVING THINGS OF THE PAST?

At expositions and fairs you sometimes see a parade of locomotives that begins with the very first kinds ever used and ends with the latest—the ones now in use. Would you like to watch a similar parade of animals from the most ancient ones down to the "latest models"? Of

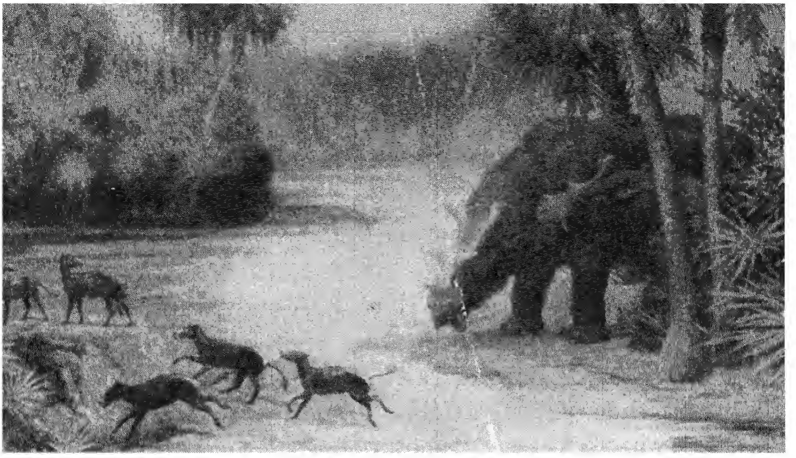


FIG. 551. In the Eocene Period in North America, small four-toed horses about the size of large dogs lived in the semi-tropical forests with the large Uintatherium. (Chicago Museum-Herbert photo)

course it would be impossible to see such a parade of the real animals. But scientists have learned so much about animals of past geological ages that artists can draw quite satisfactory pictures of many of them, and sculptors can make models of them.

In their study of the rocks geologists have uncovered fossils of many animals that are much like some of the backboned animals of today. However, such fossils are found only in layers of rock that have been rather recently made. As they work in older and older layers, the geologists find fossils that are less and less like the animals of today. Let us follow the geological story of one familiar animal. From this story you can get valuable ideas about the history of the animal kingdom.

WHAT HAS BEEN THE HISTORY OF THE HORSE? Horses are the "show animals" of the world. People love to exhibit them at shows and demonstrate how fast they can run in various kinds of races. Horses are the "show animals" of geologists, too, because their history for millions of years back can be traced very accurately. Fossil remains of early horses have been found on every

continent except Australia. The history of the horse illustrates how a group of animals survived because they could become adapted to changing environments.

Horses, as you know, are mammals whose family includes zebras and donkeys. These creatures are hoofed animals having an odd number of toes. It may seem strange to think of a horse having toes, but the foot of a horse is really a single toe with the remains of two tiny bones (splint bones) that represent other toes. You have never seen these unless you have examined the skeleton of a horse very carefully.

When you think of horses, you think of large, slick-coated, graceful animals with long legs. These modern animals are quite different from the earliest horses. The first horse of which fossils have been found appeared almost 60 million years ago in the Eocene Period (Figure 551). Fossils found in Texas show that the horses of this period were about the size of a small dog or a large house cat. In those days of long ago the horse had four toes on each front foot and three on each hind foot. Geologists tell us that there are reasons for believing that earlier horses than these had five toes on each foot. If we could see these animals with their short necks and legs, short heads, and arched backs, we would not recognize them as horses or as relatives of horses. Even their teeth were different. Instead of having large, flat grinding surfaces, the teeth were more like those of present-day monkeys and pigs. However, the structure of their fossil skeletons tells geologists that these animals really were horses.

During the Eocene Period, when these first-known horses lived, the climate was warm, and there was much moisture in the air. Semi-tropical forests were widespread. In these forests these little creatures could find plenty

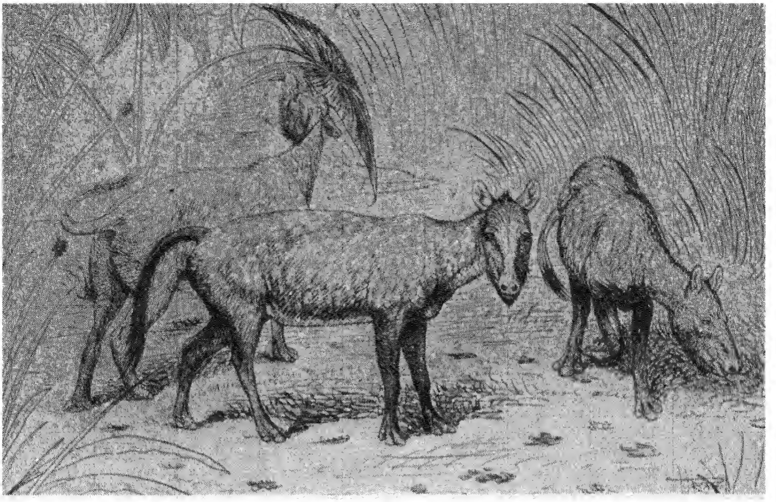


FIG. 552. The earliest known horse was the tiny Eohippus, with four toes on its front feet. (Chicago Natural History Museum photo)

of food and could escape their enemies by hiding among the trees. But slowly, over thousands of years, the climate changed. The land was raised higher above the seas, the amount of moisture in the air became less, the temperature grew colder, and most of the forests vanished. Open grassy plains took their place. Along with these changes in their surroundings came changes in the horse-like animals. Remember that these changes took millions of years. Probably many mutations appeared among these animals. Some of the mutations were of no value, or were even harmful. Others were valuable because the animals that had them were better fitted to live amid the conditions that surrounded them. The animals best fitted to live survived and reproduced; those that could not meet the changed conditions died.

During millions of years many changes took place in the horse's structure. The fossils show that horses' legs gradually became longer. Their teeth became harder and changed to flat chewing teeth, and their necks became longer. The earlier horses probably had not needed to

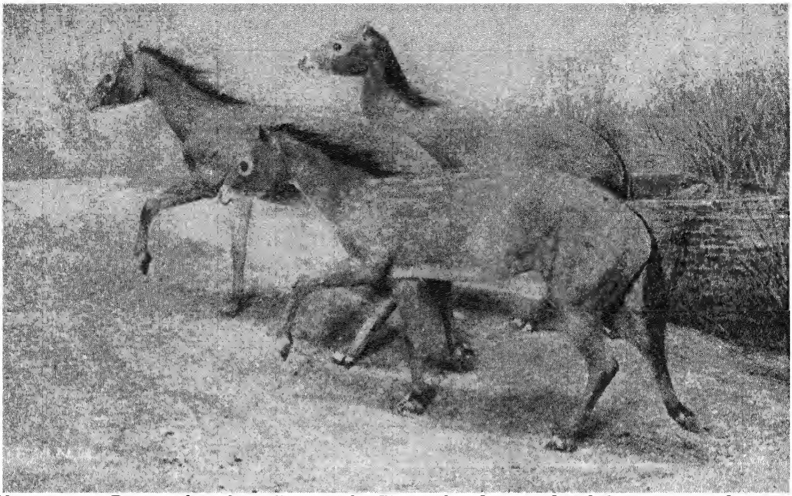


FIG. 553. Later in the Cenozoic Era the horse had become a larger animal, with but three toes on its front feet. This horse, called Mesohippus, probably looked like the ones shown here. (Chicago Natural History Museum photo)

reach the ground so easily because the thick, tall plants of the warm forests were as tall as they were. Their heads also lengthened, and their eyes were moved farther up. Their bodies became longer, and their feet changed. At first they walked with their toes flat on the ground, but gradually they began to stand more and more upon their toes. The middle toe grew long with thick, strong bones. The other toes grew smaller and smaller. Today horses walk on the ends of their middle toes. Only tiny splint bones (and fossils of more ancient horses) show us that they once had other toes. In most cases the changes resulted in better adaptation of the horse to its environment.

The story of the horse is the story of a single animal. Geologists have learned equally interesting stories about other animals, such as camels, elephants, and rhinoceroses. These stories show that remarkable changes have taken place in the structure of these animals. Geologists can piece these stories together by means of fossils and other records of the past. Perhaps now you understand better

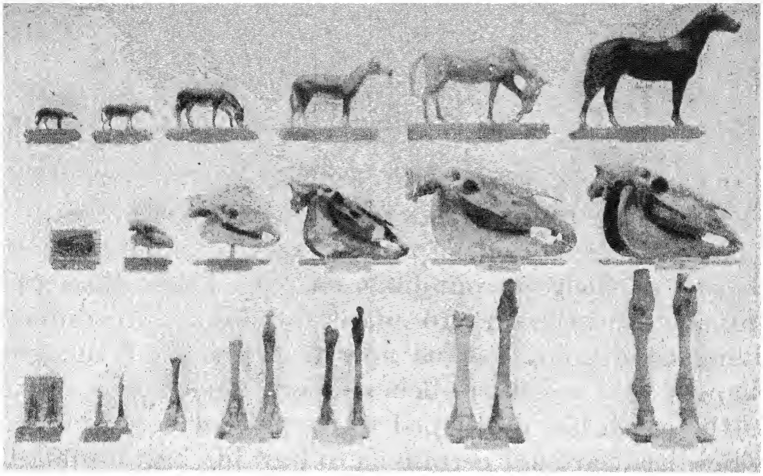


FIG. 554. Models of the different horses that have lived on the earth show how they have changed from little Eohippus to the tall, sleek race horse of today. (Chicago Natural History Museum photo)

how changed surroundings can affect the structure of animals over periods of time. The animals must either change as their surroundings change, or they die. In most cases an animal is so much like its parents that almost no change is noticeable in one generation. But when slight mutations take place from generation to generation for many thousands of years, a very different race of animals develops.

Self-Testing Exercises

1. Make a list of changes that geologists believe have taken place in horses since they first appeared upon the earth. Opposite each change describe an important change of environment that probably made this change helpful to the animal.
2. What do scientists believe happened to animals that changed in ways that were not helpful?

Problems to Solve

1. In some good reference book find a chart that shows the development of horses. Study it carefully to learn more about the development of these important animals.
2. See if you can find in reference books the geological story of the elephant.

WHAT HAVE BEEN SOME OF THE IMPORTANT EVENTS IN THE DEVELOPMENT OF ANIMAL LIFE? You have seen that over periods of millions of years animals slowly change as their surroundings change. These changes in animals are necessary to adapt the animals to different living conditions. Let us now trace some of the great changes that scientists believe have occurred in animals as the earth has developed to its present condition.

Scientists are not certain as to how life began upon the earth; neither do they know when and where it began. But we do know that ever since it began, there has been constant development from simple to more complex kinds of living things. The simplest kinds of living things probably appeared upon the earth almost 2000 million years ago (page 626). There are no fossils to show what these animals were like, but scientists find rocks made of substances that they believe must have been formed from the bodies of simple kinds of animals. Certain kinds of limestone are rocks of this sort. This leads us to believe that life existed upon the earth when these rocks were made.

The first kinds of animals were probably much like the simplest animals we find today, and of course they lived in the water because they had no way of keeping their bodies from drying up. These were very soft-bodied one-celled animals known as protozoans (see Unit 2 of this book). It was many millions of years later (in the Proterozoic Era) that animals began to form fossils. These oldest fossils are the remains of sponges. Sponges are many-celled animals. Therefore we believe that life had made great development from the one-celled protozoans to the many-celled sponges.

About 550 million years ago (in the Paleozoic Era) sea-dwelling invertebrates became abundant. Most of

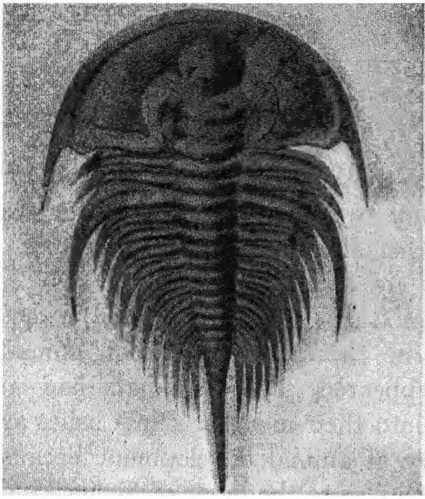


FIG. 555. The nearest present-day relative of this Cambrian trilobite is the horseshoe crab. Look at Figure 112, page 122, again. (Chicago Museum photo)

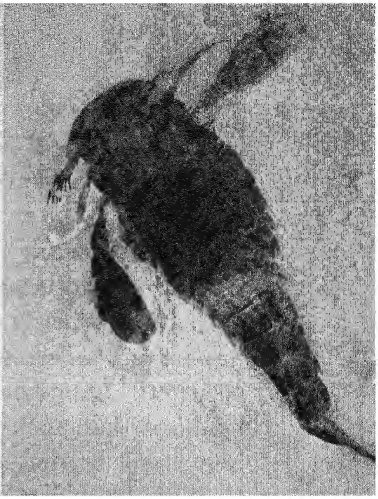


FIG. 556. A relative of the first air-breathing sea-scorpions (Photo by Dr. Ralph Buchsbaum)

these animals were early kinds of mollusks with shells and peculiar kinds of arthropods known as *trilobites*. None of these animals is living today, but Figure 555 shows one of their fossil remains. A few million years later the first animals with backbones appeared. These were peculiar fish-like vertebrates that had a kind of bony armor for protection. In 1891 the fossil remains of some of these animals were found in sandstone layers near Canyon City, Colorado. The appearance of animals with backbones was an important event in the development of animal life. Think back over Unit 3, and perhaps you can suggest some reasons why this was truly a great milestone in the history of animals.

A good many million years later (in the Silurian Period) another important event occurred: The first air-breathing animals appeared. Ever since the first animals had appeared, they had all lived in the water. These strange first air-breathers were known as sea-scorpions. They probably lived in or near the sea while they were very

young, and they took to the land when they became adults. It is interesting to know that soon after sea-scorpions appeared, other air-breathers, the ancestors of the "thousand-leggers" of today, appeared.

In the next later period (the Devonian Period) a most important milestone in the development of animals occurred. Lung-fish appeared. These animals had air bladders that opened into their mouths. These fishes are important in the story of animal development because their air bladders are similar to the lungs of higher kinds of vertebrates. Scientists who have studied the matter carefully believe that the first land animals with lungs developed from fish with lungs. Some lung-fish can still be found on the earth. They encase themselves in mud during dry seasons and breathe moist air through pores in their mud coverings. Of course, lung-fish do not have lungs like ours, but this adaptation keeps them alive during unfavorable conditions. Perhaps you may be able to see a lung-fish in some large public aquarium. Still later in this period the first amphibians appeared. Probably they developed from fish with lungs. Get some frog's eggs in the early spring and hatch them in an aquarium. As they change from fish-like tadpoles to land-living frogs, you can watch in a few weeks some of the changes that took millions of years in the first amphibians.

In the period when the most coal was being formed (the Carboniferous Period), two important milestones were reached: The first reptiles and the first insects appeared. The latter part of the period is often spoken of as the "golden age" of insects, because fossil remains show that there were many kinds and that some of them were larger than any we know today. For example, the fossil of an insect like a dragon-fly has been found in

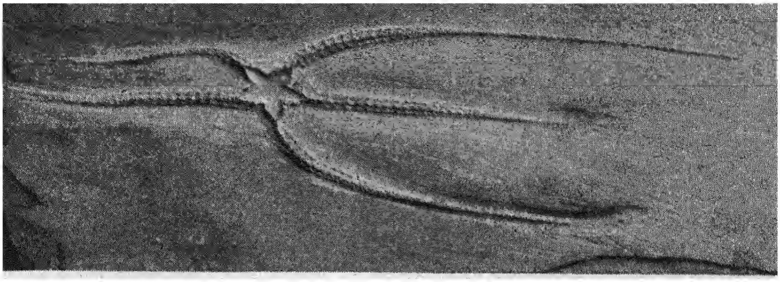


FIG. 557. A serpent star from the Devonian Period (Photo by Dr. Ralph Buchsbaum from his *Animals Without Backbones*)

Belgian coal deposits of that time. It had a wing spread of twenty-nine inches. Think of seeing an insect with wings longer than those of a crow! Fortunately, however, insects seem to have become smaller since that time. A good many millions of years later huge sprawling amphibians became the most numerous creatures on earth.

About 200 million years ago (in the Mesozoic Era) still another kind of animal dominated the earth. These animals were the kinds of reptiles known as *dinosaurs* (*dino* means terrible; *saur* means lizard). They ranged in size all the way from a few inches in length to nearly seventy feet. Some of the largest of them weighed several tons and were called "thunder lizards" (Brontosaurus) because they were believed to shake the ground as they walked. Dinosaurs dominated every kind of habitat—air, land, and water. Food was plentiful, and climates were mild; so naturally these animals prospered. Some of them were flesh-eaters, and others lived principally upon plants. At the beginning of the time when dinosaurs came to be the leading creatures, they were simple animals that could become suited to life in different habitats. Toward the end of this time their bodies began to become very com-

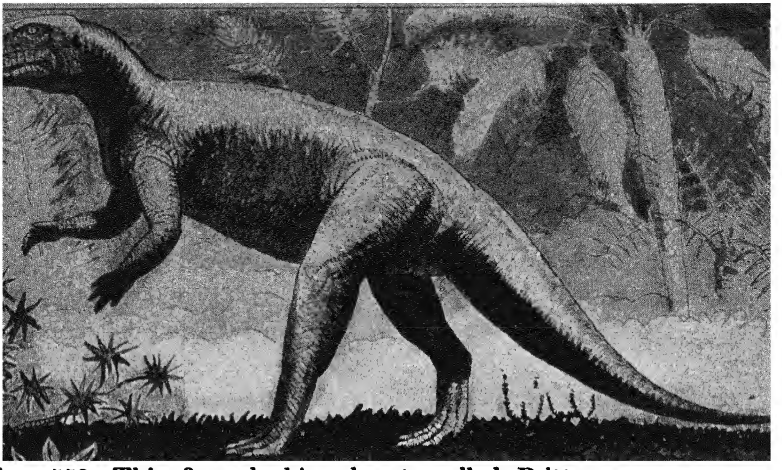


Fig. 558. This fierce-looking beast, called Psittacosaurus, was a plant-eating dinosaur. (Courtesy Sinclair Refining Company)

plex. Some kinds developed huge helmet-like armor with spikes on their heads. Others developed great plates along their backs. These plates were of value in protecting their spinal columns. Still others developed great spike-like teeth and powerful claws.

These strange, complex body parts are believed to have been one of the causes that finally lead to the complete disappearance of dinosaurs from the earth. Earlier in this problem you studied the horse as a kind of animal that has survived because it became adapted to changed living conditions. Dinosaurs illustrate the other extreme. They are a group of animals that became extinct when they could not become suited to a changing environment. Scientists do not think that any single condition caused the downfall of these animals. Toward the end of the Mesozoic Era the last great spread of seas over the land occurred. The land began to rise slowly, and most of the inland seas disappeared. The climate became cooler, and food became scarce. The bodies of dinosaurs had become complex, with their great long bony plates and covering of scales. The flesh-eaters were so big and heavy that they could not catch smaller, swift-moving animals for food.

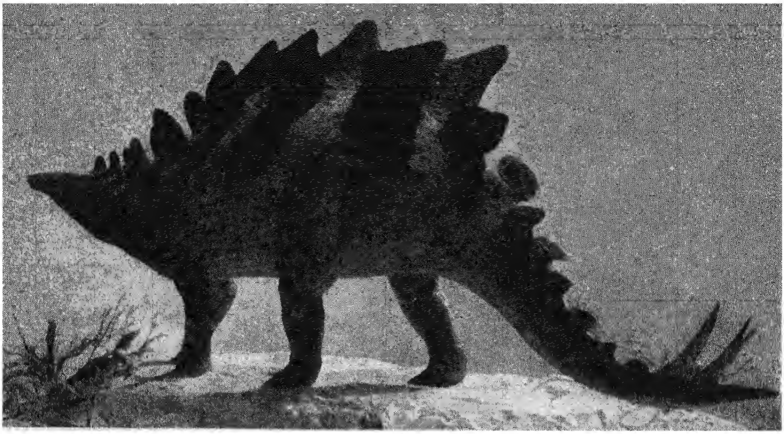


FIG. 559. Stegosaurus was one of the dinosaurs protected by great bony plates along their spinal columns. (Sinclair Refining Co. photo)

However, scientists believe that something else besides lack of food was important in the disappearance of dinosaurs. When methods of reproduction are not fitted to the conditions amid which the animal lives, these animals disappear because not enough young are produced to carry on the race. The dinosaurs laid eggs with coverings of tough membranes, much like those of turtles and other reptiles of today. Scientists believe that dinosaurs did not incubate their eggs. They let them hatch from the heat of the sun. When the climate became much cooler, not enough dinosaurs were hatched to reproduce the race. Then, too, scientists believe that small, swift-moving mammals preyed on the eggs. All of these conditions probably helped cause the dinosaurs to disappear. At any rate, no fossil remains of them are found in the rocks of the next era.

Two very important events happened during the time the dinosaurs lived. The first warm-blooded creatures appeared. These were the mammals and the birds (Figure 560). Fossils show that these creatures developed from some primitive reptile-like ancestors.

Now we come to the Cenozoic Era—the one in which we are living. During this time mammals have dominated

the earth. Early mammals gave rise to many large forms, such as the mammoth, the giant ground sloth, the whale, and the saber-tooth tiger. While this book was being written, the newspapers reported the discovery of a fossil beaver as large as a bear. During the last million years man has developed into the dominant creature upon the earth. Large mammals are gradually disappearing, and insects are increasing. Animals have come a long way in their development since they first appeared upon the earth millions of years ago. No one knows what new kinds of creatures will appear during the millions of years that are probably to come.

Self-Testing Exercises

1. No actual fossils of animals are found in the rocks formed during the first geological division of time. Why do geologists believe that some kinds of animals were living then? What kinds are they thought to have been?

2. Name several of the earliest kinds of animals whose fossils are found in rocks. Name also some of the latest kinds.

3. Why do you think the following events were important in the development of animal life: appearance of vertebrates, appearance of air-breathing animals, appearance of mammals.

4. Make a list of reasons (*a*) why dinosaurs became so plentiful upon the earth, (*b*) why they became extinct.

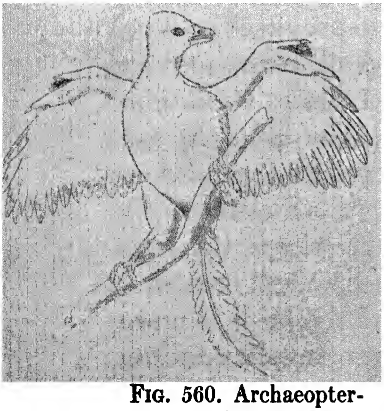


FIG. 560. Archaeopteryx, a fossil bird (American Museum photo)

Problem to Solve

Read to find out more about insects of the Carboniferous Period and about trilobites, sea-scorpions, and lung-fish. Make a report to the class on the topic that interests you the most.

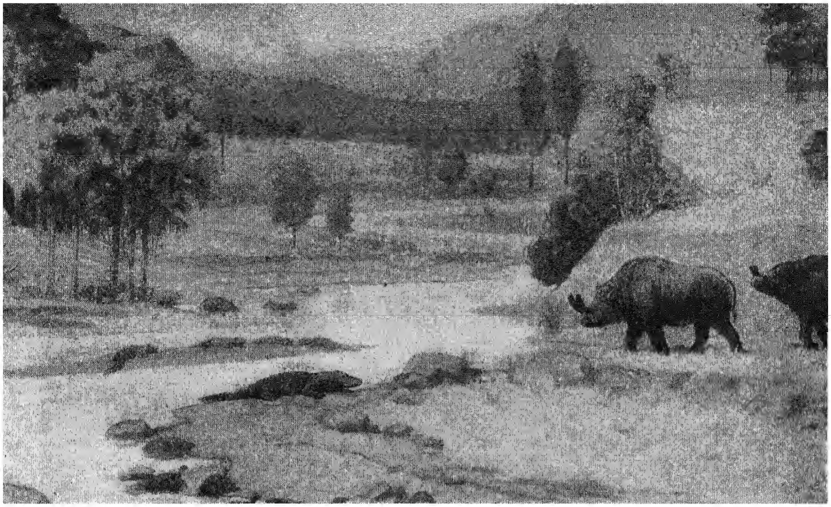


FIG. 561. In the Cenozoic Era, mammals have dominated the earth. Only a few kinds of the huge mammals that once lived can now be found. (Courtesy Royal Ontario Museum)

WHAT HAVE BEEN SOME OF THE IMPORTANT EVENTS IN THE HISTORY OF PLANTS? Since you have studied the changes that have taken place in animal life, you have probably concluded that plants have gone through similar changes. Your conclusions are correct, for fossils show that plants have developed from the simplest one-celled kinds to the wonderful flowering plants and trees of today. As was the case with animals, we do not know when the first plants appeared upon the earth. However, scientists believe that plants and animals made their appearance at about the same time, probably as far back as 2000 million years ago (Archeozoic Era). There is no fossil record of the earliest plants, which were probably bacteria and simple algae. In the Proterozoic Era the important plants were lime-forming algae. Their only remains are limestone reefs made from their secretions.

In the next long era (Paleozoic) plants showed remarkable development. Early in this era plants like the "seaweeds" of today came into being. At about the time air-breathing animals appeared, the first land plants also

Fig. 562. Tall fern-like trees and giant rushes were among the most common plants in the forests that existed during the Devonian Period. (Courtesy Royal Ontario Museum)

existed. This was an important event in the history of plants, because, as you know, land plants must have a kind of body covering that will keep them from drying out. All of these plants had spores instead of seeds for reproducing themselves. By the time the coal-forming period (Carboniferous) was reached, land forests had become common. These forests consisted of huge tree-ferns, ferns with seeds, and primitive cone-bearing trees. The forests were very dense because the climate was warm, and there was an abundance of moisture. Great shallow marshes covered much of the land. When these plants died, they fell into the marshes and were covered by mud, slime, and other plants. The carbon in them formed the rich coal beds that are so valuable to us today.

Much later, when dinosaurs were just beginning to disappear from the earth, another important milestone was reached in plant life. The first plants with true flowers appeared. Since then, during the time when mammals have dominated the earth, plants have reached their present state of development. The giant redwood trees of

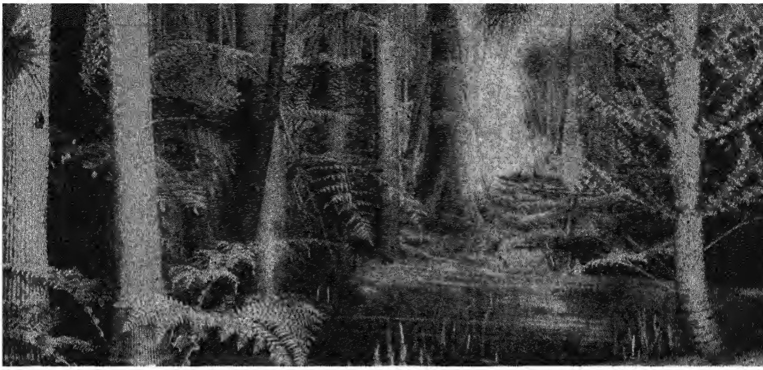


Fig. 563. In the coal-forming, or Carboniferous, Period, forests were dense with tree ferns, ferns with seeds, and primitive cone-bearing trees. (Chicago Natural History Museum photo)

California have appeared and reached the peak of their development. Many people believe that the "age of trees" has passed and that smaller shrub-like plants and open grasslands will take their place.

Here is a summary of the most important things you have learned about the history of life upon the earth for both plants and animals. It will help you remember what you have learned about them:

1. After living things got started upon the earth, they began to change.

2. These changes were often from simple kinds of living things to more complex kinds.

3. Vast numbers of living things developed adaptations to their living conditions, thrived for certain lengths of time, and then died out.

4. Fossils show that the plants and animals of today must have descended from earlier living things.

Self-Testing Exercises

1. Prepare a table that will show in one column the great geological eras and in a second column the kinds of plants that were abundant in each era.

2. Tell in your own words the main changes that have occurred in plant and animal life during geological time. Select from the text an example to illustrate each of these points.

FIG. 564. While dinosaurs were still roaming the earth during the Cretaceous Period, the earliest plants with true flowers appeared. (Courtesy Royal Ontario Museum)

3. What reasons do we have for thinking that seed plants developed later than other plants?

Problems to Solve

1. Find the story of the redwood trees. Make a chart showing events that have happened to man during the life of one of the oldest of these trees.

2. Learn more about the formation of coal. If possible, prepare, with the help of your classmates, an exhibit of coal and coal products.

Problem 3:
WHY DO WE FIND DIFFERENT KINDS OF LIVING THINGS IN DIFFERENT PLACES?

WHAT ARE SOME OF THE CHARACTERISTIC ANIMALS OF DIFFERENT REGIONS? Almost everyone knows that zebras come from Africa, llamas from South America, kangaroos from Australia, two-humped camels from parts of Asia, and reindeer from the cold regions of Europe, Asia, and North America. Also, certain kinds of plants come from each of these different places. Many parts of the world are nearly alike in regard to tempera-

ture, amount of rainfall, seasons, and the kind of land surface. Yet, even though many places are very much alike as to climate and other conditions, each region has its own peculiar kinds of plants and animals that are found in no other places. Let us examine some of these places briefly.

Australia has its tropical and temperate regions, its forests, its open plains, and its mountains. South America and Africa (south of the Sahara Desert) have similar regions. What are some of the characteristic animals you would find in these similar places? Are they alike, or are they widely different? Let us first see what we find in Australia. In Australia and some of its neighboring islands we find the only egg-laying mammals in the world, the duckbill, or platypus, and the spiny ant-eater. Kangaroos and their relatives, some forty different species, including wallabies, wombats, and strange creatures known as bandicoots, are peculiar to this continent. When we say that an animal or plant is *peculiar* to a place, we mean that it is found there and nowhere else. Also, dasyures, koalas, "flying mice," "flying" phalangers, and dugongs (a kind of water mammal) are there. Even the names

Fig. 565. "Splash," a famous Australian platypus, belongs to the strange group of mammals that lay eggs. (Courtesy Mr. Mason Warner)

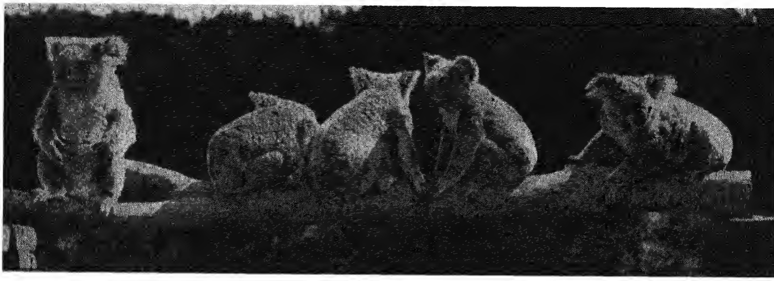


FIG. 566. These five little koala bears are natives of Australia where they spend most of their lives in the eucalyptus trees. (Courtesy Mr. Mason Warner)

of these animals seem strange; and they are strange, for such creatures are found nowhere else except in zoos.

Stranger than their names, however, is the fact that all of these animals belong to the oldest groups of mammals living today. Bats and dingo dogs are the only higher mammals native to this continent. Bats could migrate to Australia because of their wings, and dingo dogs are believed to have been brought to Australia by early peoples as they migrated from other parts of the world. Of course, many of the plants belong to species that are different from those of other continents. In other words, Australia and its neighboring islands have characteristic kinds of plants as well as characteristic kinds of animals.

In South America, with similar climatic and other features, it seems that there should be animals similar to those of Australia. As you know, however, such is not the case. Here, tapirs, llamas, ant-eaters, primitive monkeys, peccaries, sloths, and a host of other native animals are found. Giant and "six-banded" armadillos are also peculiar to this continent. Armadillos are found in only one other place in the world, southwestern United States, and these are different from the armadillos of South Amer-

ica. The animals you have just read about are not found in Australia. They are found in South America only, and a few of them in near-by parts of Central America. Also, much of the plant life is different from that of other places.

Africa (below the Sahara Desert) also has its temperate and tropical regions, with mountains, forests, and open plains. Here, again, in spite of surroundings that are similar to those of the two other continents you have studied, we find a different set of native animals and plants. If you have seen a movie or a book with pictures of African animals, you will recognize these as typical: giraffes, elephants, wart-hogs, antelopes of many kinds, rhinoceroses, zebras, lions, leopards, one-humped camels, and many different species of *primates*, such as gorillas, chimpanzees, and monkeys. West of the Kalahari Desert, hyraxes and aard-varks are characteristic animals. The aard-varks and the entire giraffe family are found in no other region in the world. Like the animals of South America, those of Africa appeared later than those of Australia.

Of course, other continents with their varied regions have animals, and plants as well, that are characteristic. For example, we think of redwood trees, coyotes, badgers, American buffalo or bison, and Rocky Mountain sheep as belonging to certain regions of our own country. However, Australia, South America, and Africa (below the Sahara Desert) were used as examples because each of these continents has similar climatic regions and other features that allow us more easily to make comparison of plants and animals living on them.

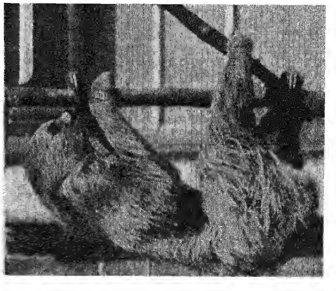


FIG. 567. The sloth travels in this upside-down manner.

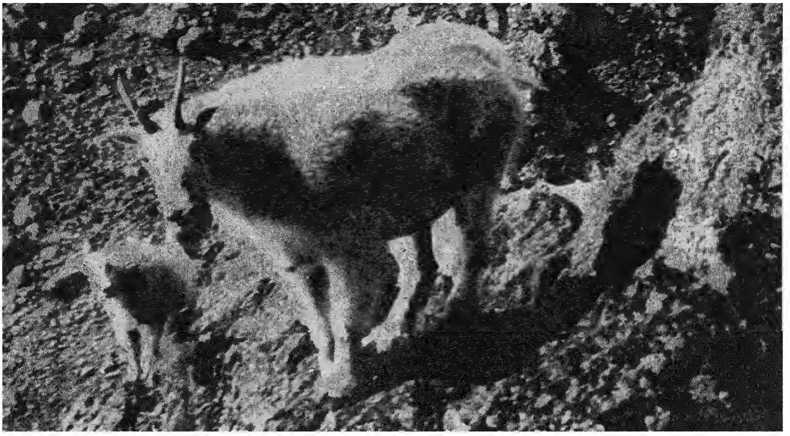


FIG. 568. The shy Rocky Mountain goat is rarely photographed in its inaccessible home, but because the mother was protecting her baby, the photographer was able to get very close. (Acme photo)

Self-Testing Exercises

1. Tell in your own words what is meant by saying "that each region has its own peculiar plants and animals."
2. Which of the three continents used as examples in this part of the unit has the most primitive animals? Try to think of some reasons for this. Save your answer for later use.

Problem to Solve

Make an enlarged outline map of the world. On this map paste pictures and write the names of animals and plants that are peculiar to the different regions. Use the animals that are listed in this book and consult references to find others.

WHAT CONDITIONS HAVE CAUSED DIFFERENT KINDS OF LIVING THINGS TO BE FOUND IN DIFFERENT PLACES? You have learned that living things thrive best in places where it is easiest for them to find the materials and conditions necessary for life. When you first think of the question asked at the beginning of this part of the unit, the answer seems easy. It seems that animals and plants will always be found in all the places to which they are best adapted.

But many kinds of animals could live in places where they are not now found. Why do they not live there?

What has kept them from spreading to every place where they could live? And how have they spread to the places where they now live? About 200 years ago only very primitive animals, such as those mentioned earlier, were found in Australia. Now, however, many animals of later origin are found there. They were brought by settlers, and they have thrived so well that they are crowding out the older types of animals.

Rabbits are not native to Australia, but now they are pests. Along with other animals, they are slowly but surely causing the older types of native animals to become extinct. There were no starlings or English sparrows in America until about 100 years ago. But the fact that these birds were not found in America earlier does not mean that they were not suited to the living conditions here. They are very much suited to these conditions, as their rapid multiplication shows.

What are some other reasons for the appearance of different kinds of living things only in certain regions? The answers to this question are found in the geologic history of the earth. From your study of this unit so far, you have learned that the boundaries of continents have not always been the same as they are now. (See Table 6.) At times land has risen high above the water, and at other times seas have come in over the land. For example, geologists believe that many million years ago Australia and its neighboring islands were connected to Asia by a wide neck of land.

These ancient land connections are sometimes called "land bridges," for animals could migrate over them from one place to another. Primitive mammals are believed to have migrated to Australia when it was a part of the mainland. Later this land bridge sank into the ocean, and

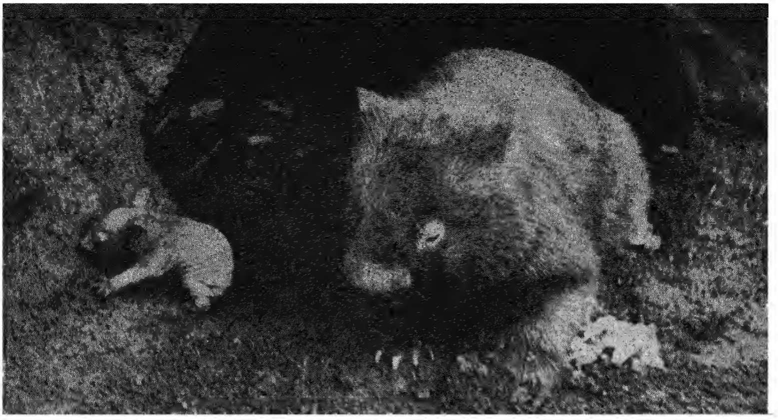


FIG. 569. The mother wombat, shown here with her still furless baby, is not such a strange-looking animal as one might expect from the name. (Courtesy Mr. Mason Warner)

the animals in Australia could not escape. As other animals appeared in different places in the world, they could not reach Australia. So the primitive animals on this continent were isolated. From them the present group of animals originated. Thus the isolation of Australia has caused it to have the strange group of native animals found there.

Scientists believe that horses originated in North America and migrated to other countries by means of land bridges. Later these land bridges were destroyed, and for some unknown reason horses all died out on this continent. Then there were no horses until the white man brought them from Europe. Still later the land bridge between Alaska and Asia appeared again, and some scientists believe that even the earliest men came to our continent over this bridge, which has since been destroyed as the land sank beneath the seas. So the formation of land bridges and their later disappearance have caused different kinds of animals to be found in different places. The sea was a barrier which animals could not cross.

Land may also act as a barrier which keeps animals from spreading. For example, the Isthmus of Panama has

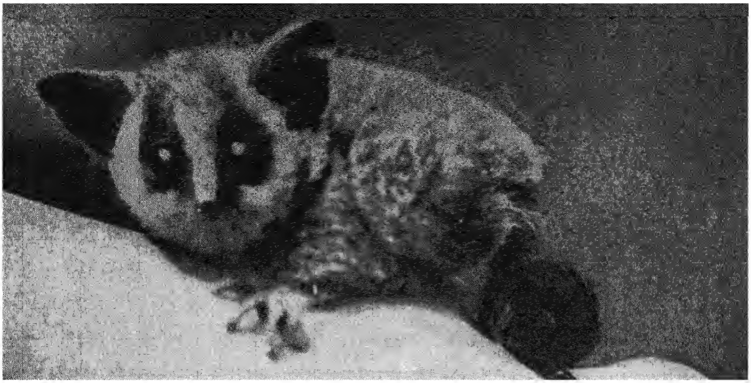


FIG. 570. Besides the large animals always associated with Africa, many small ones such as the galago, or "bush-baby," are peculiar to the African forests. (Acme photo)

kept marine animals from migrating between the Atlantic and Pacific Oceans. Many of these animals could not stand the cold waters through which they must pass in migrating around the tip of South America. As a result, we find in the Pacific Ocean animals that are related to, but distinctly different from, those in the Atlantic Ocean. In the case of land animals, long chains of mountains sometimes keep animals from migrating from one part of a country to another part of the same country. On one side of the mountains certain species have become adapted to the conditions there and are different from their relatives on the other side of the mountain chain.

Deserts may serve as barriers to keep animals from spreading freely over a continent. For example, the Sahara Desert keeps the animals of South Africa from spreading into North Africa, and those in the north from migrating to the south. Certain animals from the southern part of this continent might be able to live in the northern part, but they are not able to cross the desert with its unfavorable conditions. Therefore, the animals on the two sides of the desert have remained separated, and each has become adapted to conditions in the places where

it lives. In this way, over long periods of time, different kinds of animals come to live in different parts of this continent.

From your study of this part of the unit you find that many happenings cause different animals to be found in different places over the earth. Some of these are:

1. The coast lines of continents change through long geologic ages with the appearance and disappearance of land bridges. These changes isolate certain kinds of animals. After their isolation, these animals change and become different from those of their kind elsewhere. Plants, too, have undergone similar changes, but it is easier for you to understand what has happened if animals are used as examples.

2. Land may act as a barrier which water animals cannot cross. Thus different kinds of animals are found in different places over the earth.

3. Deserts may act as barriers to keep animals from spreading over a continent.

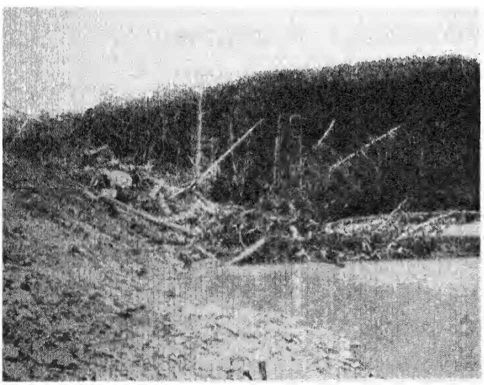


Fig. 571. A modern glacier, destroying a forest in its path, shows us what must have happened to the vegetation during the advance of the great Ice Age glaciers. (U. S. Geological Survey photo)

Self-Testing Exercises

1. Give examples to show that the absence of animals in a given region does not mean that these animals could not live there.

2. How do you explain the fact that the most primitive animals on earth are found in Australia? Compare your answer with the answer you gave to Self-Testing Exercise 2 on page 652.

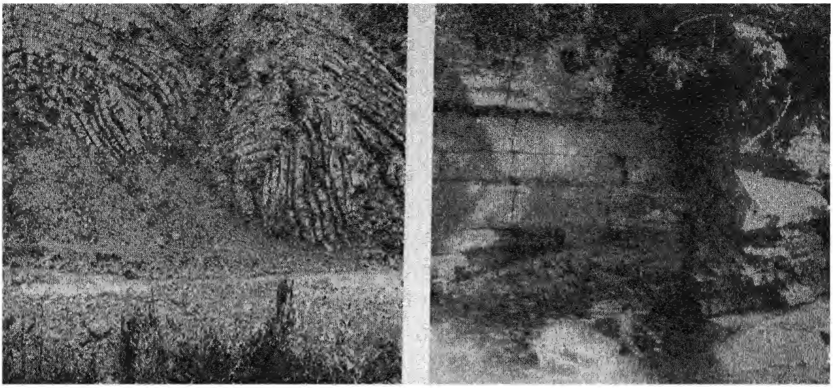


FIG. 572. What stories can these pictures tell geologists about the past history of the earth in these particular localities? (U. S. Geological Survey photos)

3. Make a list of reasons why different animals appear in different places over the earth. Opposite each reason write a brief explanation.

Problems to Solve

1. Read about plants and animals that have been introduced into our country by man.
2. Find what animals have become extinct in recent years. Try to account for this.

LOOKING BACK AT UNIT 11

1. Copy the headings of the sub-problems of this unit. Then write a brief paragraph to answer the question asked by each sub-problem.
2. List the order of classification of animals in Unit 2 (from the simplest to the most complex). Compare this list with the order of the appearance of animals upon the earth, as shown in the Geologic Time-Table on page 626.
3. Show by using them in sentences or by other means that you understand the meaning of each of these words:

era	*carboniferous*	*dinosaur*
land bridge	*sea-scorpion*	*lung-fish*
radioactive element	*oldest known rocks*	*platypus*
primitive animal	*period*	*geologic history*
geologic column	*unconformities*	*metamorphic rock*

ADDITIONAL EXERCISES

1. Make a collection of sedimentary, igneous, and metamorphic rocks that are found in your locality. Use a geologic map from your state geologic survey to find the approximate ages of these rocks. Be sure to keep careful notes as to where each specimen came from to help you in telling its age.

2. Make a collection of fossils. Try to identify them by means of pictures in reference books.

3. Make a booklet showing different kinds of dinosaurs that lived on land (marshy and dry), in water, and that could soar or fly through the air. Write your own descriptions of these animals and tell something of the conditions under which they lived. Try to reconstruct some of these animals from clay or papier-mâché.

4. With the aid of the members of your class, try to learn the geologic history of your surroundings. Use state or United States government bulletins and geology textbooks to help you.

5. Make a special study of the egg-laying mammals.

6. Make a special study of the *marsupials.* Why are they thought to be an old type of animal? Give several reasons.

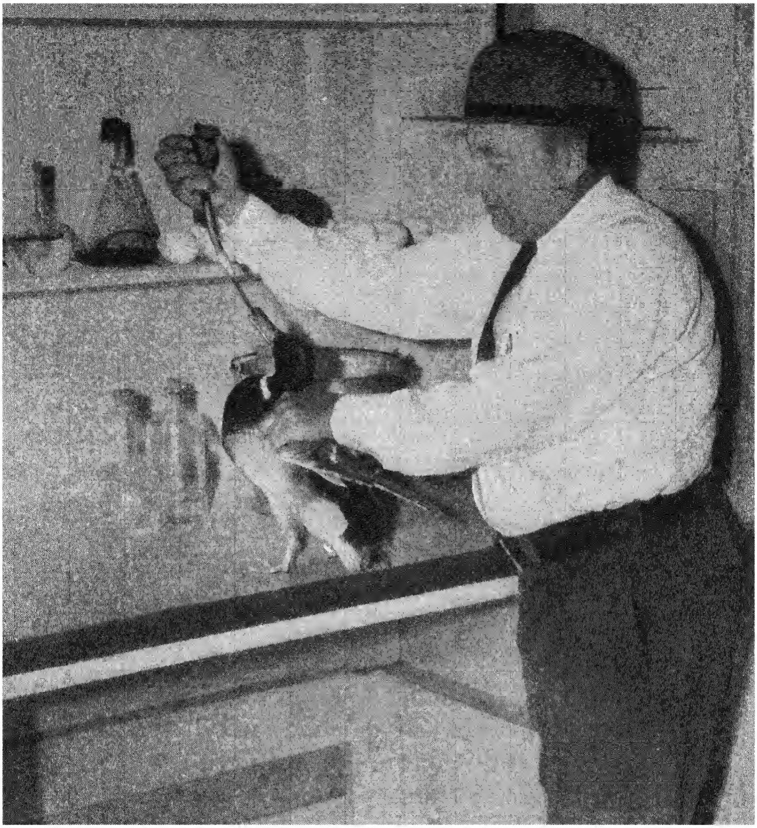


FIG. 573. When ducks at the Bear River Migratory Waterfowl Refuge in Northern Utah get sick, they receive excellent care at the "duck hospital." This duck is being treated for "western duck sickness," a disease that has killed great numbers of ducks. And the doctors at this hospital do not mind being called "quack" doctors either. Steps are being taken by local communities, the states, and the National Government to preserve the wild life of the nation. In this unit you will learn about the various aspects of the conservation problem and what you can do to help solve it. (Courtesy *Popular Science Monthly*)

UNIT TWELVE

UNIT 12

HOW CAN SCIENCE HELP US KEEP FROM WASTING NATURE'S WEALTH?

INTRODUCTORY EXERCISES

*1. How is the balance of plant and animal life maintained? Describe ways in which man upsets this balance.

*2. What is meant by the term *extinct animal?* Try to name some animals that are extinct because of things that man has done.

*3. What is crop rotation? Make a list of reasons why crop rotation is a valuable practice.

*4. Name some ways in which soil is moved from one place to another. Which of these ways do you think are most important in changing the surface of the earth? Give reasons for your answers.

*5. What is *top-soil? Sub-soil?* In which of these do plants grow better? Why?

*6. During a severe flood or rain-storm, which of the soils in Exercise 5 would be damaged more? Why?

*7. Make your own definition of *erosion*. List some ways in which soil erosion is being (or could be) checked in your own community.

8. Does *conservation* mean not using trees for lumber, coal for fuel, land for farming, and not hunting and fishing? Give reasons for your answer.

9. Copy the table below on a separate sheet of paper. In the left-hand column list all of the conservation problems you know of that occur in your community. In the right-hand column suggest ways of trying to solve these problems. Save the exercise for later use.

Conservation Problems of My Community	Ways of Trying to Solve These Problems
1. *Erosion is taking away some of the best soil from hillsides.* 2. Etc.	*Making the rows run around the hill instead of up and down it.*

Fig. 574. By building check dams these children are helping to prevent soil losses by erosion. The dams slow down the movement of water and give it more time to soak into the soil, and they also keep gullies from spreading. Check dams may be built of any available materials—rocks, brush, logs, or sod. (Photo by H. Mieth and O. Hagel from *Life*)

LOOKING AHEAD TO UNIT 12

When you take a trip through different parts of the country, you enjoy seeing well-kept farms with their luxurious crops. You like to drive through the cool shade of wooded regions. On your vacation you love to visit clear lakes and sparkling streams where there are fish to be caught. You want to hike through woods where wild animals can be seen. Of course, there are many places like the ones you have just read about.

However, on any long trip you are sure to find places that are entirely different. In many localities the soil is worn out, and the crops are poor. Gullies are slowly eating into the hillsides and making the land a desolate waste. In other places there are no trees, and even the covering of grass or other vegetation is gone. Perhaps dust-storms sweep across the land in dry weather, and floods may come suddenly when the rains are heavy. Unfortunately, places like the one you have just read about are becoming all too common throughout our country.

For thousands of years before white men came to America, the soil of our country was slowly building up.

Plant roots kept it from washing away, and decaying animals, leaves, and plant bodies added their material to make it rich. Of course, Indians raised crops before the white men came, but there were only about 500,000 Indians in all of what is now the United States.

When white men settled the Atlantic coast, they began to cut down trees for building materials and to clear fields for crops. The vast forests before them seemed inexhaustible. There was plenty of land; so new fields were cleared when the old ones began to produce poorer crops. Fire was often used to clear forest growth. This destroyed trees and other vegetation over large areas and ruined much organic matter that had protected the surface of the land. Animals were slaughtered in large quantities, for the supply seemed greater than could ever be used.

As settlers began to spread westward over the country, the senseless destruction of natural resources spread with them. But the supply still seemed inexhaustible. And so civilization spread to all parts of the land, carrying with it the waste of soil, forests, animal life, and other natural resources.

All of this unwise use of resources has brought us face to face with serious problems. Our forests are almost gone; our land is being washed away; our supplies of coal and oil are being used up; our wild animals are disappearing; and floods and dust-storms have become a national problem. The worst feature of the whole problem is that once the destruction is started, it gets steadily worse and worse. Wild animals have disappeared from many places because their homes and breeding places have been destroyed and because people have been unwise in their hunting. Many streams have been "fished out" because fishermen were not satisfied with catching a reasonable number and put-

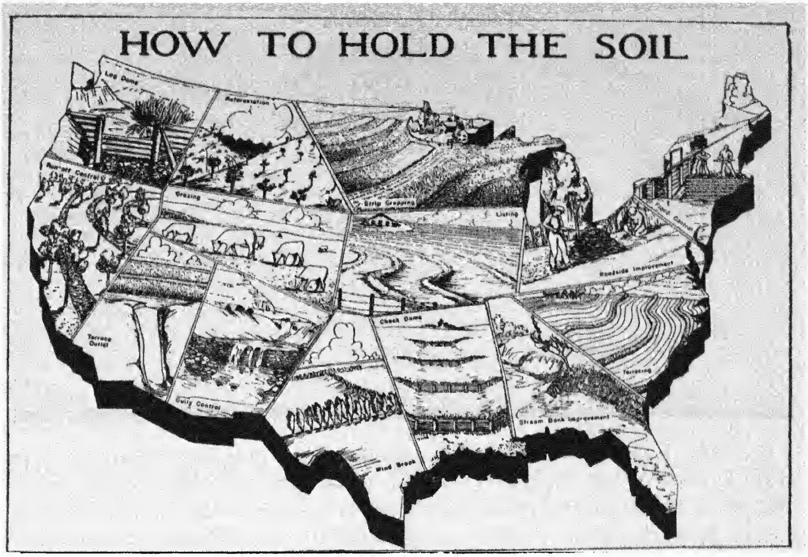


FIG. 575. The first problem of this unit will explain why some of the methods shown on this map for saving soil are effective. (Soil Conservation Service photo)

ting back the fish that were too small for use. What are we going to do about this waste of our natural wealth?

About forty years ago a few scientists began to be alarmed at what was happening. They tried to get people to understand the importance of the problem and to plan far enough ahead to avoid exhausting the natural resources of our country. Most people paid little attention to them. In recent years, however, the protection and wise use of our natural resources has become so important that the national and state governments spend millions of dollars each year on *conservation*. In addition, they are trying to make people everywhere understand the need of conservation.

Your part in this important work is (1) to learn what some of the important problems of conservation are; (2) to learn some of the ways of solving these problems; and (3) to help by putting what you have learned into practice in your community.

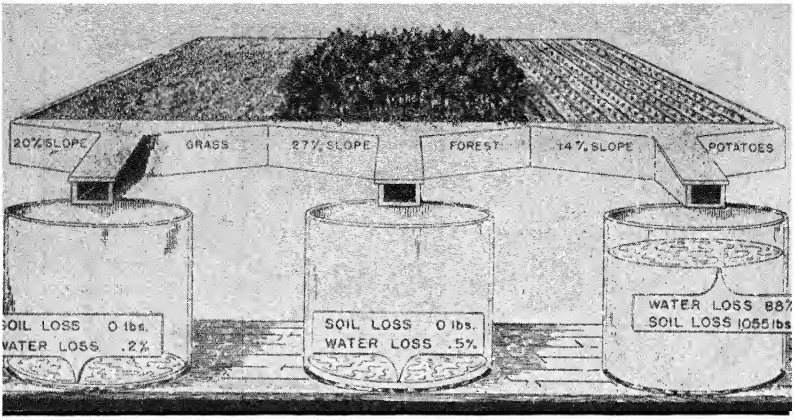


FIG. 576. This chart shows the results of studies carried on by the Soil Conservation Service Station near Ithaca, New York, from March 1 through 19, 1936. The studies compare the soil and water losses from land of varying slope and under different vegetation. (Soil Conservation Service photo)

Problem 1:
HOW CAN WE SAVE OUR SOIL?

EVERY rain-storm and every dust-storm in our country carries some of our valuable soil away. With each rain Iowa, Wisconsin, Illinois, and other near-by states are sending some of their soil to the Gulf of Mexico. Parts of Michigan, Indiana, Ohio, and other states are giving soil to the Great Lakes. The eastern states are losing soil to the Atlantic Ocean, and the extreme western states are losing it to the Pacific Ocean.

In most places in our country the average depth of the soil is from three to six feet. Of this, only about eighteen inches, or the upper layer, known as *top-soil*, is suitable for growing plants. If a truck load (one or two cubic yards) of soil is taken from an acre of land each week, you can scarcely notice it. But if this goes on for thirty years, about a foot of soil will be removed from the entire surface of the land. In some places we are losing soil this fast, and even faster. Fortunately, however, erosion is occurring more slowly in most places.

This loss of soil is a very serious matter to every one of us, because we depend upon the soil either directly or indirectly for food. In order to study the problem intelligently, you will need to know first of all something about the conditions that cause soil erosion.

WHAT ARE THE CONDITIONS THAT CAUSE SOIL EROSION? Over fifty-nine tons of rich soil per acre may be lost in one year from an acre of farm land that is planted in corn! This is almost unbelievable, yet government tests show that it is true. A test showed that only eight tons were lost in one year from an acre of similar land on which the crops were rotated. What causes this difference in the amounts of erosion? It is not merely that different kinds of crops are planted, for there is no single cause of soil erosion in any one place. At least four different things affect erosion: (1) the amount of rain that falls and when it falls, (2) the slope of the land, (3) the kind of soil, and (4) the kind of farming that is carried on.

It is easy to understand that the amount of rainfall affects erosion. Some regions of the United States have an average of fifty inches of rainfall a year, while others have an average of only twenty inches a year. Of course, we would expect more erosion in regions of 50-inch rainfall. But a large amount of rainfall well distributed throughout the year will not cause nearly so much erosion as heavy rainfall in short periods. For example, the rain gauges at the Soil Conservation Experiment Station at Arnot, N. Y., showed that on June 19, 1936, an inch of rain fell in ten minutes. This one rainfall washed 7586 pounds of soil from one experimental plot of land. In the next six weeks only 1.7 inches of rain fell on the same area. During that whole six weeks there was little, if any, erosion. Thus most erosion occurs during seasons of heavy rain.

Another important factor in erosion of soil is the slope of the land. You know that water always moves to the lowest possible level because of the pull of gravity. If the slope is steep, the water runs faster than if the slope is gentle. You know also that the faster water is moving, the more soil it can carry with it. Even on long, gentle slopes water gains speed as it runs downhill. Also, the volume of water is greater toward the bottom of the slope. Thus, even on land that is sloping gently, rich, loose top-soil may be carried down to lower levels and finally to streams.

The problem the farmer faces is to get the rain water to soak into the ground or to run to the lower places without taking his soil along. And the steeper the slope, the greater his problem is. To solve the problem, the farmer must study the *contour* (shape of the surface) of the land. From the contour of the land he can plan which way to run the rows, where to put strips of grass or other cover crops, or where to put his drainage tile or ditches.

A third important factor in erosion is the kind of soil. Coarse soils, such as sand and sandy loam, absorb water more easily than most other kinds of soil. Therefore, these soils are not likely to suffer from erosion so much as the finer soils, because water sinks quickly into them instead of running off and carrying the soil with it. However, if a coarse soil is nearly all sand with no finer particles to help hold it together, much erosion will occur during heavy rains. Humus and other organic matter added to soil act as a sponge and help hold moisture.

Clay and clay loams do not absorb water quickly. They are made of such tiny particles that they pack together tightly and form a hard surface. Rain falling upon such soils runs off easily and carries much soil with it before it can sink into the ground. Perhaps you have seen streams

FIG. 577. If the farmer plants corn, cotton, or other crops that leave the land bare between the rows, or if he plows his land in the fall and exposes it to the winter rains, erosion may occur very rapidly. (Soil Conservation Service photo)

that run over clay soils. You know how muddy they are after a heavy rain. Once the tiny particles are in suspension in the water, even water that is moving slowly can carry them great distances. The farmer who has fine clay-loam soil probably has better farming land, but his land will be much more easily damaged by erosion than if it were made of coarse, water-absorbing soils.

The fourth factor that affects erosion is the way the farmer manages his crops. If he keeps his land planted in grass or other crops that have masses of fine roots, erosion will be kept down to a considerable extent. Government tests show that an acre of one kind of land planted in bluegrass lost only 100 pounds of soil during a year. Similar land on which other kinds of crops were planted (corn and cotton, for example) lost much greater amounts of soil per year. Leaving some of the land in woods helps greatly. Tree roots help hold the soil, and the covering of leaves that fall help to hold moisture and prevent erosion.

The use of crop rotation or a combination of crops, such as cowpeas planted in corn, helps reduce erosion. The United States Department of Agriculture has carried

on experiments to discover which crops best prevent erosion. Grass, alfalfa, clover, trees, and shrubs will do the most toward checking erosion. The next best are oats, wheat, rye, and barley. The poorest are row crops, such as corn, cotton, potatoes, tobacco, and truck crops.

From your study of the unit thus far you can see why soil erosion is a complicated problem. It depends upon several different factors, and each of these factors varies from place to place. Perhaps you can look around you now and discover something about erosion in your own community that you had never noticed before.

Self-Testing Exercises

1. Why does the amount of rainfall play an important part in erosion?

2. Why does the distribution of rainfall according to months affect the amount of erosion? Give an illustration.

3. Explain what is meant by the contour of land. How does the contour affect erosion?

4. What kinds of soils erode most easily? Least easily? Why?

5. With what kinds of crops grown in your locality do you think the soil washes away the least? With which do you think it washes away the most?

Problems to Solve

1. Examine places in your community where erosion is taking place and where it is not occurring. Do your findings agree with your answer for Self-Testing Exercise 5? Why?

2. (*a*) Is erosion a serious problem in your community? In your state? (*b*) If so, are land-owners aware of the problem?

3. Try to get a government contour map of your locality from the U. S. Geological Survey in Washington, D. C. Study the contour of the land where you live. Find (1) the highest places, and (2) the lowest places. Visit different places in the locality where erosion is taking place. Mark these places on the map.

FIG. 578. Contour farming, in addition to controlling soil erosion, makes field work easier on the farmer, the teams, and the machinery, since they are traveling nearly on a level instead of up and down slope. (International Harvester Company photo)

WHAT ARE SOME OF THE WAYS OF CONTROLLING SOIL EROSION? Did you ever hear anyone use the expression, "trying to fit a square peg into a round hole"? He was probably speaking of trying to make something work that would not work as he wanted it to. That is exactly what has been done in farming in the past. We have tried to lay all our fields off in squares or rectangles, that would not fit around hillsides or sloping river bottoms. The result was hard work for the farmer and his animals in cultivating fields and the loss of much soil. When rows run up and down hillsides, heavy erosion takes place with each rain. The rows form channels in which the water can run faster down the hillsides.

In recent years there has come into use a way of laying out fields so that the rows go across the slopes of hills instead of up and down. This way of plowing is known as *contour farming* (Figure 578). When you think of it, this seems the most natural way to plan fields. Rows that go across slopes form many little dams that hold the water when it rains. In this way much of the water can sink into the ground instead of rushing down and washing soil

away as it goes. Furthermore, seeds are not so easily washed away in contour farming as in the older straight rows. Many a farmer has planted seeds in rows that ran up and down a hill, only to have them washed away before they could germinate and get their roots firmly anchored in the soil.

Another method of preventing soil erosion is *strip cropping*. This way of planting includes contour farming, as you will see. Instead of planting crops in large fields, the crops are planted in strips of uniform width. Like the rows in contour farming, these strips run across the slope and not up and down (Figure 579). Strip cropping has a special advantage. Strips of crops like corn, tobacco, or potatoes have strips of grass, wheat, or soy-beans in between them. Soil that is washed down from the cleanly cultivated crops is stopped by the thick growth in the strip below. Experiments show that the width of the strips may vary from fifty to about 125 feet. In general, narrower strips should be planned for steeper slopes. If the strips are very wide, gaps may wash out in individual strips just as they would on a bare hillside.

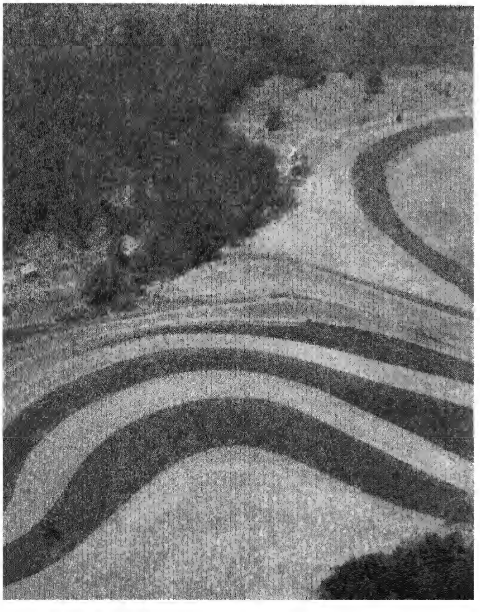


FIG. 579. An aerial view of a farm in South Carolina shows how the fields have been laid out carefully for alternate strips of alfalfa and corn. (Soil Conservation Service photo)

FIG. 580. This fertile wheat-field has well-built terraces to protect it from excessive water run-off and erosion. (Soil Conservation Service photo)

Strip cropping has two other advantages. Crops are easier to cultivate and harvest, and they may be rotated more easily. For example, the strip that was planted in corn the first year may be planted in grass or wheat the next year; while the strip that was planted in grass or other small grain the first year may be planted in corn the second year, and so on. In this way many different kinds of rotation may be planned to keep the soil fertile while the stripping is helping to prevent erosion.

Still another method of preventing soil erosion is *terracing* (Figure 580). When this plan is used, the long, steep slopes of hillsides are built into short, gradual slopes something like steps. The rows of crops on the terraces go around the hillside. In most terracing, shallow drainage ditches that follow the contour of the land must be provided on each terrace. These ditches lead the water into a general drainage outlet in the field.

Careful farmers use many other simpler devices to prevent erosion. They plant winter cover crops, such as rye, wheat, and other similar crops, to keep down much erosion during the season when rains are plentiful. They leave steep slopes for pasture or for wood lots. Permanent pasture crops are an ideal solution to the erosion problem

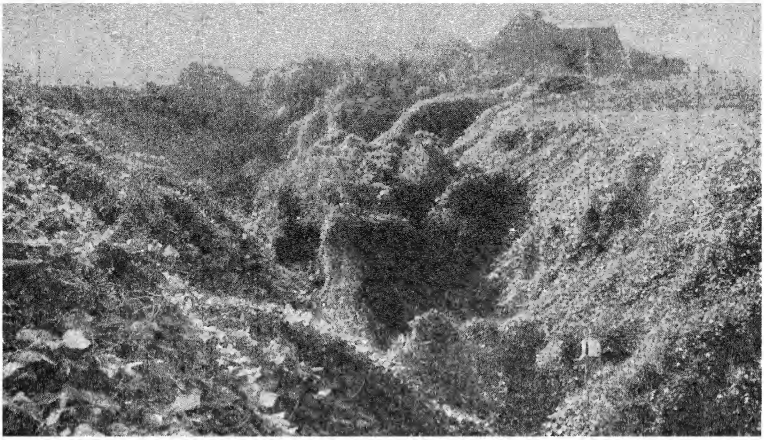


FIG. 581. Kudzu, a leguminous vine, has been planted in this forty-foot gully to prevent further erosion. Kudzu is often used because it grows and spreads quickly. (Soil Conservation Service photo)

in places where the steep slope of the land makes the raising of other kinds of crops unprofitable because of erosion. In many permanent pastures soil experts have found it wise to plow deep furrows at intervals around the steep hillsides. Such furrows hold water and let it sink into the soil. Tests show that pasture furrows let water go from six to eighteen inches deeper in soil than it will go in pastures with no furrows.

Another way of helping prevent erosion is planting grass in drainage ditches. Grassy coverings in ditches and other waterways hold back the water until it flows so slowly that little erosion occurs. Also, the roots hold the soil in place. Trees, shrubs, and vines along fence rows, in the bottom of gullies, and at the heads of gullies help check or prevent erosion. Shrubs planted around the edges of fields also help hold the soil.

In all of this discussion of controlling soil erosion, there are two things to keep in mind: (1) No single method is of much value by itself, and (2) the methods to be used must be determined by the kind of land and its particular features.

HOW CAN A FARMER PLAN HIS CAMPAIGN AGAINST SOIL EROSION? One of the first things you would do if erosion was taking away much of your best soil would be to study your farm carefully. You would want to find the causes of the damage. Some of the things you would want to know would be: Where is erosion taking place? At what seasons does the most erosion occur? What is the contour of the land? Next, you would want to find what methods other people have found successful in checking erosion. You would talk with farm agents and soil experts. You would attend farm meetings to hear the problems of erosion discussed, and you would get bulletins from the United States Department of Agriculture, from your State Department of Agriculture, or from Regional Headquarters of the Soil Conservation Agency nearest you.

You would study all these methods carefully to be sure that you were planning wisely, for it would be expensive, and probably disastrous to your land, to go at the problem in a hit-or-miss manner. You might terrace land that was too steep for terracing, or you might use crops that were not suited for checking soil erosion. As you studied, you would try to make a plan that would fit your particular farm. You might get a soil expert to look over your land and check your plan to see that you were on the right track.

Then, if you were a scientific farmer, you would take a third step. You would experiment with a

Grass 48 Feet Long Found; Offers Aid Against Erosion

New York, July 10.—(AP)—Discovery of the Leviathan of all grasses, a single strand that grew forty-eight feet along the earth's surface, is announced in Nature, Britain's official science journal. This strand sent down roots every few inches and from them grew blades up to three feet tall. Nature says this grass offers a new aid to stopping soil erosion. The grass was found in East Africa and is a cousin of Bermuda grass grown in the southern states.

FIG. 582

FIG. 583. Among the several new grain and forage crops that are adapted to the plains, and that may be grown on large expanses to control erosion by wind, are the sorghums. (Soil Conservation Service photo)

few acres of land here and there in places where erosion was worst. In this way you would see whether your plan was worth carrying out on your whole farm. You would test different methods to see just what crops and which ways of managing your land were the most profitable to use. Undoubtedly you would have to change your original plans several times, just as any other experimenter does in trying to solve his problem. If you planned to use strip farming, you might find it better to use narrower strips. Perhaps contour farming would be better suited to the slope of your land than the terracing that you had first planned to use.

Last of all, you would put what you had learned into practice on your entire farm. However, you would still keep studying the problem to see whether you were getting results, and you would change some of your methods as you learned better ways of fighting erosion.

Perhaps you are thinking that all of this is too much

trouble. That is just what many other people have thought, and it is one of the reasons why people all over the country are facing serious erosion problems. However, if you were making your living by farming and you saw your land produce smaller and smaller crops because your best soil was being lost, you would "tackle" the problem in a scientific, business-like way.

Self-Testing Exercises

1. Close your book and write a brief paragraph telling what each of the following methods of cultivation is and how it helps prevent soil erosion: contour farming, strip cropping, and terracing. Then check with the book to see if you have omitted any important points.
2. Why does each of the following prevent loss of soil: *winter cover crops, permanent pasturage, planting grass in drainage ditches, and planting or leaving wood lots?* Think of some of the disadvantages of using these methods.
3. Without consulting your book, outline the steps you would undertake in solving a problem scientifically. When you have outlined these steps, show how you could use them in trying to stop erosion on a farm.

Problems to Solve

1. Write to your state experiment station or to the United States Department of Agriculture for bulletins on the control of erosion. Read them to learn details that could not be given in this book.
2. With the help of your classmates, work out a conservation project to use in stopping soil erosion on your school ground or in some other place where it is a problem.
3. Make a special study of terracing as a method of controlling erosion.
4. Is maintaining soil fertility true conservation? Write a composition in which you discuss this problem.

Problem 2:

HOW CAN WE SAVE FUEL FOR FUTURE USE?

IN ONE YEAR nearly 500,000,000 tons of coal were mined in the United States. In the same year 1098.5 million barrels of crude petroleum and 1,916,595 million cubic feet of natural gas were taken from the ground. These figures seem so staggering that we can scarcely believe them, but the report from the United States Bureau of Mines shows that they are true.

When we use coal, petroleum, and natural gas, we are drawing upon the energy savings of the past, and these energy savings cannot be replaced when they are gone. Just how long our present supplies will last no one knows. Scientists believe that our present supply of coal will probably last from 1000 to 4000 years, and that the supply of oil will last for a much shorter time. Coal and petroleum provide about 95 per cent of the energy used in our country. Since we depend so largely upon these materials for our energy supply, and since we cannot replace these materials when they are gone, we face another very serious conservation problem.

One thing is certain: We will continue to use our natural fuels as long as they last. Our chief problem, then, is to learn how to use them so that we can get the most good from them with the least amount of waste. Here the coöperation of science and industry is most important. Science must find the most efficient ways of using fuels, and industry must put into practice what is learned.

HOW CAN THE SUPPLY OF COAL BE CONSERVED? Before you can study this problem intelligently, you need to know something about the kinds of coal. The first stage in the formation of coal is *peat*. This substance contains from fifty to sixty per cent of carbon and from

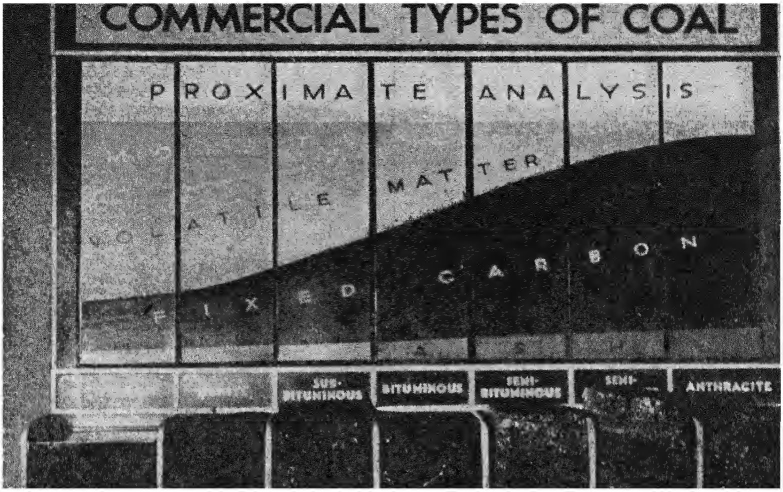


FIG. 584. At the Museum of Science and Industry, Chicago, is this exhibit showing composition of different kinds of coal. *Volatile matter* is the part that escapes as gas when the coal is heated.

twenty-eight to forty-eight per cent of oxygen. The rest of it is hydrogen, nitrogen, and mineral elements. The next stage is *lignite*, or brown coal, the next *bituminous*, or soft coal, then *anthracite*. Anthracite is the hardest coal of all. It is about ninety-five per cent carbon, with the remaining five per cent hydrogen, oxygen, and nitrogen. In general the greater the per cent of carbon in coal, the greater its heating value. Bituminous coal is the most widely used kind, especially for industrial purposes. In addition, coke, gas, and other very important by-products are made from it.

For many years we have each year wasted enough coal in the United States to supply all of the homes in our country for another year. This amount of wasted coal would keep all of our railroads in operation for about eight months out of the year. One of the greatest sources of waste was in mining. One scientist estimated that only about fifty per cent of the coal in mines was ever taken from the ground. This left almost half of our coal supply in the earth, where it will never be mined. Safer and

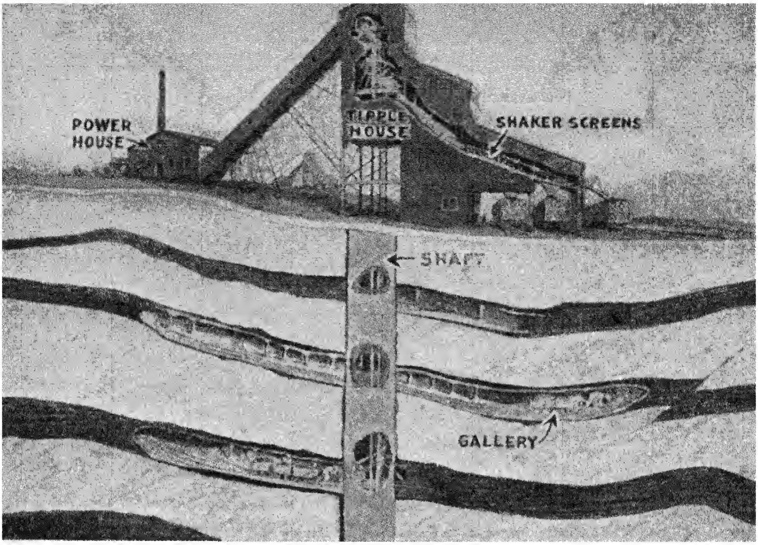


Fig. 585. When it is necessary to sink deep shafts underground in order to get the coal out, it is called shaft mining. It is easy to understand the difficulties of getting more than fifty per cent of the coal from the earth by this method. (Courtesy *Scientific American*)

more thorough methods of mining have been introduced to make more of our entire coal supply available. By using these methods we can save a great deal of coal for future use.

Another way of conserving our coal supply is by using it economically. Let us see how our coal supply is now being used. Industrial plants use the greatest amount, railroads the next greatest amount, coke manufacturers next, homes next, public power plants next, and the manufacturer of gas least. We also sell some coal to other countries, but not much. Chemists tell us that about thirty-five per cent of the energy from burning coal goes up the chimney. This amounts to several hundred million dollars each year.

One of the ways of saving much of this waste is by making coke from the coal and using the coke for fuel. As the coke is made, such by-products as gas, coal tar, ammonia, and others are given off. These can be saved

and used in various ways. For example, coal tar can be made into liquid ammonia, creosote, and various kinds of oils. Other products, such as dyestuffs, perfumes, and paints, can be obtained from these substances.

Coke is an excellent fuel. It burns with very little smoke, and since it contains as much as 85 per cent carbon, it gives off a great amount of heat when it is burned. Coke is used in blast furnaces for extracting iron from iron ore and for other heating purposes where great amounts of heat are needed. So one way of conserving coal is to make it into coke. In this way both the coke and the valuable by-products can be used.

Another way of saving coal is by regulating the amount of air that gets into the fire. The hottest fires need just the correct amount of oxygen for each pound of coal that is burned. Too much air causes too rapid burning, which lets much of the heat escape up the chimney. Too little air and other wrong conditions cause smoke. When black smoke is formed, unburned carbon (soot) is going up the chimney. Special ways of feeding coal into furnaces and special ways of admitting air eliminate much of this waste. Since the greatest amounts of coal are used by industries, it is in manufacturing plants that most coal could be saved. However, this does not mean that anyone, in the smallest home or in the largest industrial plant, is justified in using coal in wasteful ways. The laws require that every boiler must have a steam gauge and a safety valve to prevent explosions. Why not have and enforce laws requiring people to use devices for saving fuel?

Still another way of saving coal is by having very large power plants use coal to produce electricity and then distribute the electrical power to the small plants that

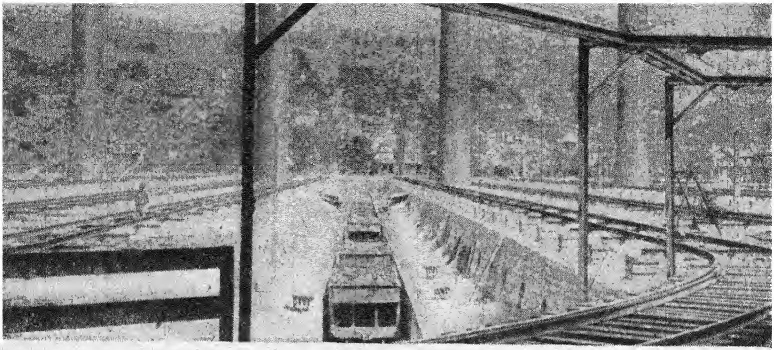


FIG. 586. Coke is made from soft coal, which is heated in ovens like these from which most of the air is shut out. The tracks on top are for the cars that drop the coal into the ovens. (© Keystone View Co.)

need it. Tests have shown that large power plants are six or seven times as economical as small plants. This is just one illustration of how science can help save fuels. You learned on page 529 that steam turbines are much more efficient than ordinary steam engines. They use about twenty-eight per cent of the energy of fuels. Wherever possible, the more efficient turbines should be used. In this way less fuel will be used to get the energy we need.

Another way of saving fuel is by substituting water power for steam power. On page 511 you learned that only a small amount of the available water power in the United States is being used. In spite of the disadvantages of using water power (page 511), more of it can be used as better methods of transmitting electricity are developed. Artificial fuels, too, will help save coal. And even wood still has a place as fuel. In sawmills and woodworking plants waste wood can often be used as an economical source of power.

Self-Testing Exercises

1. Make a list of the ways of saving coal that are suggested in this part of the unit. Try to think of some of the advantages and disadvantages of putting each of these methods into operation.

2. Explain why making coal into coke and using it for fuel helps conserve our fuel supply.

3. What other sources of energy can we hope to use in the place of coal? (See Unit 9.)

Problems to Solve

1. In some good reference book find what by-products (including those mentioned in this book) are made from coal. Try to find out how some of these by-products are made.

2. What methods of coal conservation are in use in your community? Suggest how other methods could be used.

3. Make a map of the United States showing the location of the principal coal fields.

4. Make a booklet about coal. Your booklet may include kinds of coal, its uses, methods of mining, etc. Use pictures from magazines and other sources to illustrate your story.

5. In a reference book read how coal is mined. List any suggestions for improvements in mining methods.

HOW CAN OUR SUPPLY OF OIL BE MADE TO LAST AS LONG AS POSSIBLE? In the United States alone over 16 billion gallons of gasoline are used by automobiles in one year. As you have learned, scientists do not know how long our present supply of oil will last because they do not know how many more oil deposits may be discovered. Several hundred years is a good estimate, at least. When we think of the vast amount of petroleum that is used each year, we wonder what man will do when this valuable natural resource is gone.

Not only is petroleum used for making gasoline. Much of it is used as *fuel oil* for operating Diesel engines and for heating buildings. In addition, many valuable by-products are made from petroleum. Lubricating oils of various kinds for machinery, petroleum jelly (Vaseline) for salves and medicine, paraffin for waterproofing, canning, and

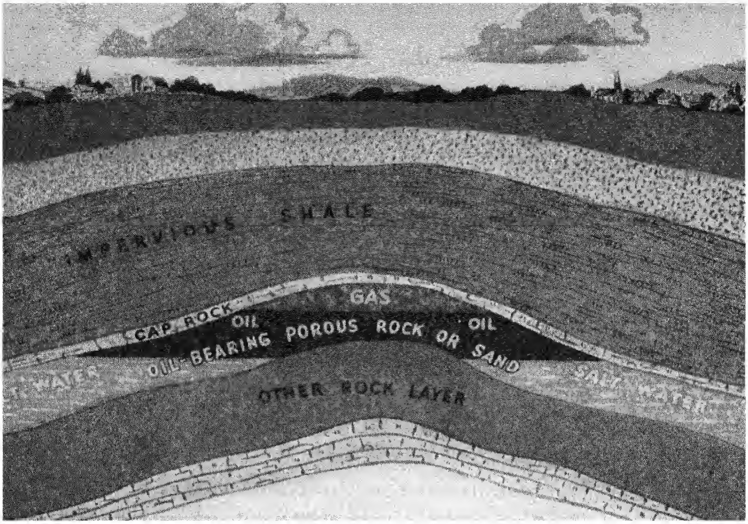


FIG. 587. Oil-bearing layers of rock

other household purposes, gasoline, naphtha, kerosene, and even one kind of chewing gum are but a few examples. Since petroleum is so important to us, do you wonder that scientists and engineers are trying to find ways of conserving it?

Most people have strange notions about how we get oil from the ground. The popular belief is that pipes are driven down into huge underground lakes of oil and that the pressure of the earth makes the oil gush out. What are the facts? Hundreds or thousands of feet down in the earth are huge domes of rock layers (Figure 587). At the tops of these domes gas, which is lighter than oil, collects in porous sandstone. The gas cannot escape; so it exerts great pressure in all directions. Below the gas are other layers of porous rock or sand that hold the precious oil like a sponge. Beneath the oil-bearing layers is usually salt water, which is heavier than oil. Salt water also exerts pressure on the porous oil-bearing sand. Under natural conditions the pressure of the gas from above and of the salt water below "squeezes" oil from the oil-

bearing sand or rock and makes it flow up through the pipes of the well.

The oil prospector comes along and uses sensitive instruments to help him estimate where the dome is. Then drills are used to bore down through the dome, and pipes are sunk as the drilling is done. The drill usually reaches the gas pocket first, and billions of cubic feet of valuable gas are allowed to escape so that the oil can be reached. Then the drill reaches the porous rock or oil-soaked sand, and the oil either spouts out under natural pressure or is pumped out. Finally, salt water begins to come up. People used to think that when this happens, the well is "through." But, actually, about seventy-five per cent of the oil still remains in the ground, never to be brought to the surface and used.

Here is where scientific conservation methods come into the picture. About 1903 a clever mining engineer got the idea that if the gas in the top of the underground pocket could be kept in, the pressure it exerted on the porous rock or oil sand (plus the pressure of the salt water from beneath) would continue to force oil out of the ground. He found a way to force gas into a well that seemingly had "gone dry." Much to his delight, he found that the well began to flow again. By this method in most cases fifty per cent more oil can be taken from wells. What a saving this is! And what is more, when the oil is really exhausted, a great reservoir of natural gas still remains. This gas can be used whenever it is needed because the pipes keep it under control.

All of this sounds as if an important part of our oil-conservation problem is solved. But, unfortunately, such is not the case. For every well that uses this method of re-pressuring, there are ten that do not use it. Much needs

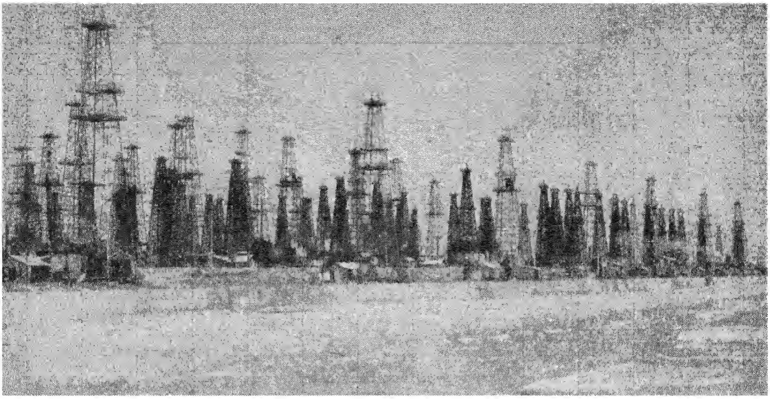


FIG. 588. Study this figure to see how many wells are fed from a single pocket or dome. This is a cause of great waste. Owners of near-by wells will all have to agree to return gas to their wells and thus keep up the pressure in the entire field. (Bureau of Mines photo)

to be done to convince operators that re-pressuring is an economical thing to do. Also, well-owners have to learn to coöperate with each other to make this method a success. When an oil well is found, everyone who owns or controls near-by land drills wells. This is done so that each owner will get as much oil as possible before the supply gives out.

Remember that this method of getting most of the oil from wells (instead of leaving it in the ground as lost) can be used in two ways: (1) Old wells can often be re-pressured and the remaining oil obtained from them, and (2) on new wells the method can be used to make the wells yield most of their oil. Still another method of getting oil from the ground is by treating almost exhausted wells with acid to increase their yields. This method is being used in several places.

Not only must we get all of the oil possible out of wells that are already being used, but we must use oil wisely after we get it. Science has found a way of saving oil in the production of gasoline. It is called *cracking*. To crack oil, the oil is heated under great pressure to temperatures higher than the boiling point of gasoline. The high tem-

peratures break up the heavier oil molecules into lighter gasoline molecules. "Cracking" oil gives almost twice as much gasoline from a gallon of oil as plain distillation gives. This process makes our valuable oil go farther in providing supplies of gasoline.

Undoubtedly substitute fuels will come into use as the supply of oil becomes smaller and the price rises higher. Alcohol can be made from crops that grow each year and can be mixed with gasoline to drive automobiles. Its use in this way is being tried in Japan in limited amounts now. Much gasoline could also be saved by using smaller engines in our automobiles. However, so long as gasoline is not too expensive, substitute fuels and smaller motors will probably not be used. So we shall have to rely upon increasing our yields from oil wells and upon discovering new ones to add to our supplies for the present.

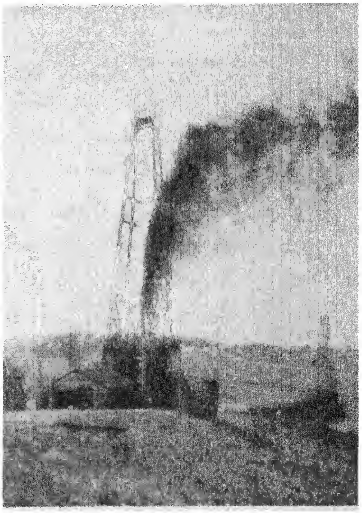


FIG. 589. The practice of wasting the natural gas that is found with oil by burning it is gradually being abandoned. (Bureau of Mines photo)

Self-Testing Exercises

1. Tell in your own words why oil flows out of an oil well under natural conditions.
2. What petroleum products have you used or seen used? Try to add others to the list that is given on pages 681-682.
3. Explain how an oil well may be re-pressured.
4. Close your book and make a list of all of the ways you can think of in which oil may be saved. Check with other sources, and add other ways.

Problems to Solve

1. How do drillers of oil wells keep the oil and gas under control? Look in reference books and science magazines.

2. Read in some good reference books to learn more about "cracking" oil. Make notes on your reading and prepare an oral report for your class on this topic.

Problem 3:
HOW CAN WE BEST ENJOY OUR WILD ANIMALS?

OVER 100 years ago Andrew Jackson, then president of the United States of America, issued a Thanksgiving Proclamation in which he gave thanks for the unlimited supply of wild life. Today we find that many of our wild animals are gone. The supply was far from unlimited. Our birds, small fur-bearing animals, large mammals, fish, and other wild creatures have disappeared at such an alarming rate that we must do something about it. Unless people everywhere recognize how serious the problem is, practically all of our wild life will become extinct. You have already learned that the dodo, the passenger pigeon, and the heath hen have disappeared because of man's destructiveness. Others will soon follow. Instead of giving thanks for the unlimited supply of wild life, the people of our country must now try to find ways of conserving the kinds of wild life that are left.

The United States Department of Agriculture and many private organizations, such as The Audubon Society of America and The More-Game-Birds-in-America Foundation, have attacked the problem. But organizations such as these mentioned above cannot accomplish this difficult task alone. Each citizen must learn what his part is in the plan of conservation and then do it. How can we attack the problem in a scientific manner? What is your part in helping to solve it?

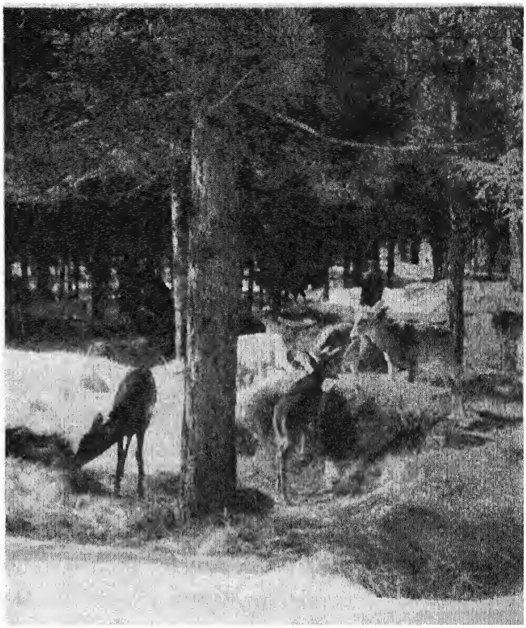


Fig. 590. In many forest refuges in Wisconsin, feeding stations are provided for the deer. (Wisconsin Conservation Department photo)

WHY ARE OUR WILD ANIMALS DISAPPEARING SO RAPIDLY? One of the first things to do in solving a problem is to find what is causing the trouble. Why is our wild life disappearing so rapidly? One reason is that we have destroyed their breeding and feeding places. For example, industrious farmers practice *clean farming;* that is, they cut all the bushes and weeds in fence corners, along ditch banks, and at the edges of woods. This has destroyed the places where quail, prairie chicken, and other birds can nest, feed, and find shelter. Many scientists think clean farming is one of the most serious causes of destruction of bird life. Under older methods of farming, when rail fences were in use, things were different. There was space in fence corners and other places where plants could grow and protect the birds. Of course, we cannot go back to the old days of rail fences. That would be a waste of wood. But it is possible to restore the bird population in as little time as ten or fifteen years if we go about it properly.

The same thing is true of animals, such as deer, bear, raccoons, beavers, bison, and many others. For example,

white-tailed, or Virginia, deer are noted for their habit of seeking the shelter and protection of forests. Since forests have been destroyed to such a great extent, the numbers of these animals have greatly decreased. The draining of swamps and ponds has robbed beavers of their natural habitats and has caused their complete disappearance in many places. Up until about 1870 great herds of bison inhabited the plains of our country. With the coming of civilization these animals were killed in great numbers. In 1900 only a few hundred wild bison and probably one thousand captive animals were left. The American Bison Society has worked very hard to keep these animals from becoming extinct, and today several thriving herds of bison are in existence. This is a good example of how wisely planned efforts can save animals from extinction.

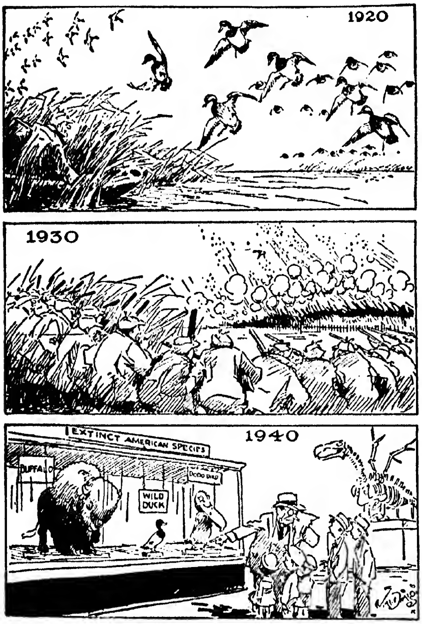


FIG. 591. Wasteful hunting may result in the disappearance of the wild duck. (Courtesy *New York Herald Tribune*)

In addition to saving the natural habitats of birds and other wild life, there is something else we must do to help them. The natural enemies of animals, game birds in particular, have been increasing. Stray cats and harmful kinds of hawks are good examples. Remember, however, that not all kinds of hawks are harmful. Some people try to kill any kind of hawk they see. This is very unwise,

because there are only three kinds of hawks that are believed to be definitely harmful to other birds. These are the sharp-shinned hawk, the Cooper's hawk, and the duck-hawk. The first two destroy small game and poultry, while the duck-hawk destroys large numbers of water-fowl. The American goshawk is a native of Canada, but it comes to the United States in the winter and destroys game birds. Other kinds of hawks are either entirely helpful or do as much good as they do harm. The main thing to remember here, however, is that natural enemies of many of our game animals are increasing, while the opportunities for the game animals to increase are becoming less and less.

Another very important reason why wild life is decreasing so rapidly in our country is the methods of hunting, fishing, and trapping that are practiced in many places. Conservation of wild life does not mean that our people should not hunt, trap, and fish. It means that people who hunt, trap, and fish either for pleasure or to earn a living must use common sense in their methods. Truly, man is the worst enemy of many of the things that are most valuable to him.

The invention of more effective guns, traps, and fishing equipment has added to the destruction of our game. Have you ever heard sportsmen boast about the number of fish they caught or the number of birds they killed? These people are often the ones who complain the most that all of our wild life is disappearing. They enjoy hunting and fishing, yet they are unwilling to do the things that need to be done in order that they may continue to enjoy their sport. All the sportsmen, as well as everyone else, must work together if we are to succeed in saving our wild animals.

Self-Testing Exercises

1. Make a list of reasons why wild life is disappearing so rapidly in most places. Which of these reasons apply to your own locality? Add others that are not given in your book.
2. What are some of the natural enemies of wild life in your neighborhood?

HOW CAN WE FIND WHICH ANIMALS SHOULD BE SAVED? You have learned earlier in your science work that where man does not interfere, there is a balance of numbers among the wild plants and animals (see *Science Problems, Book 1*, pages 400-405). In trying to find what animals should be protected, we must not overlook this important principle. If we do overlook it, we may make matters even worse. For example, you have learned how man has upset the balance of nature by introducing rabbits into Australia. Another example occurred in the Kaibab National Forest, in Arizona. Rangers and hunters killed all the enemies of the deer. As a result, the deer multiplied in numbers until there was not enough food for them all. Hundreds starved to death.

Some of the questions we should ask about an animal before we decide to protect it are: Is it of value to sportsmen? Is it of practical value to man for other purposes than hunting? Will it add to our pleasure when we see it on hikes and field trips? What effect will protection of this animal have on the natural balance?

Here is an example of a scientific way of discovering whether an animal is helpful or harmful to man. Experts from the U. S. Department of Agriculture have examined the contents of the stomachs of hundreds of red-shouldered hawks. This bird was believed by many people to be harmful. What do you suppose the experts learned? About ninety per cent of the food of this hawk

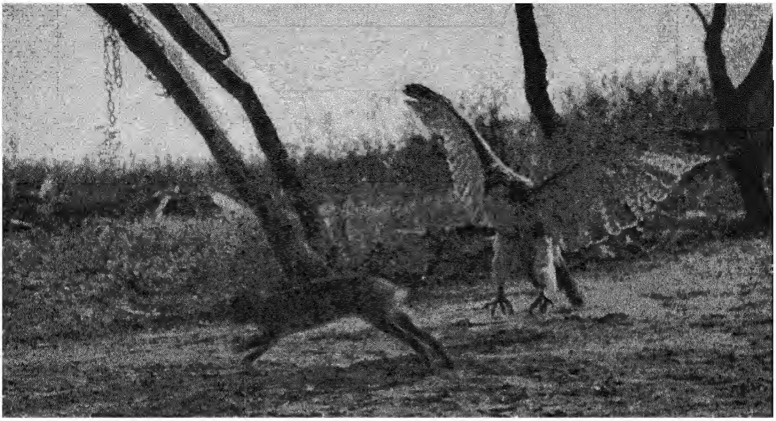


FIG. 592. Like a bolt from the blue, the red-shouldered hawk swooped down on the rabbit. (Pix-Laws photo)

consists of animals that injure our crops or pastures, and only about one and one-half per cent of its food is farm poultry or game animals. Surely a bird that does this much good must be saved! Be sure to note, too, the scientific way in which the facts were learned. When we deliberately decide that certain wild animals must be destroyed, we cannot make our decision by "hearsay" or what someone merely thinks. We must have scientific evidence about their helpfulness or harmfulness and about their effect on the balance of life in the community.

This method has also been used to find what wild animals use for food. Many kinds of animals, for example, minks and weasels, occasionally steal poultry. But more often they pay for their damage by eating great numbers of field mice and other small animals that destroy our food plants. Similarly, skunks feed upon mice, grubs, and harmful insects, while badgers feed upon ground squirrels, small burrowing animals, and insects. So now, when we want to find which animals are helpful and which are harmful, all we have to do in most cases is consult books that have been written by people who have studied the facts with care.

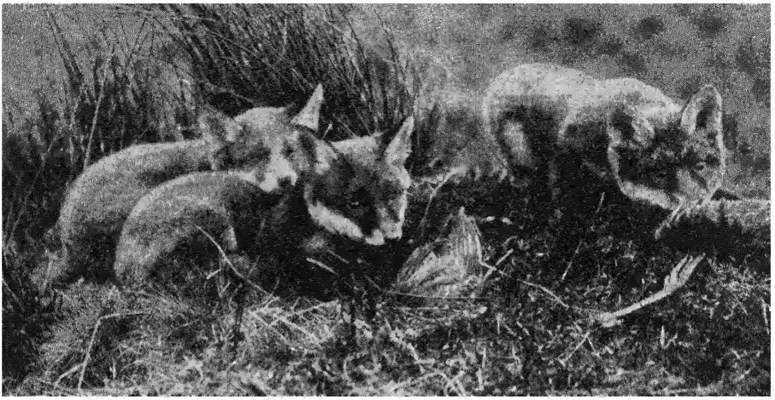


Fig. 593. Baby silver foxes, valuable as fur-bearing animals

Before we decide whether a certain kind of animal should be protected, we would want to know also whether it has enough natural enemies to keep it in check, or whether it is likely to become a pest. It is very unwise to bring new animals into our country or to try to increase the numbers of certain kinds of animals unless expert biologists are consulted. These biologists study the problem carefully and make experiments to be sure that an animal will not increase to such an extent that it will become a pest. The mongoose of India was brought to Jamaica and other near-by islands to destroy rats, lizards, and snakes. Later it became a great pest. It ate chickens, birds, small farm animals, and sometimes fruit. The same thing can happen if we allow certain kinds of native animals to increase too rapidly. Therefore our national and state governments employ specialists to study the problem of conservation from all angles to find how increased numbers of animals will fit into the scheme of living things.

Some of the important game animals of our country are deer, bear, moose, foxes, wolves, wildcats, and even rabbits. A few of these, such as wolves and wildcats, are considered harmful and are not protected in most places.

Many animals are of value as fur producers. These should be preserved at all times and hunted only according to carefully planned game laws. The important fur-bearing animals are minks, weasels, otters, skunks, muskrats, wolverines, badgers, raccoons, foxes, bears, and martens. The important game birds are quail, grouse, wild turkeys, pheasants, and ducks. Other kinds of birds are valued for their songs or for their beautiful plumage.

We have not tried to make a complete list of all the kinds of wild life that should be protected. Fish, oysters, shrimp, and many others could be added. We have tried to make two things clear to you: (1) We have tried to show you some ways of finding what kinds of animals should be conserved, and (2) we have given some examples of these kinds of animals. Undoubtedly you will think of many reasons as to why particular animals need protecting in your locality.

Self-Testing Exercise

Explain why the problem of conservation should be studied carefully in trying to find what animals need to be protected.

Problems to Solve

1. Make a list of (*a*) wild animals that you consider helpful in your community, and (*b*) those that you believe to be harmful. Give your reasons for placing them in either list. Read government bulletins or other references to see whether you agree with them about the animals you have listed.

2. With the help of your classmates find what animals are now protected by law in your community. Add to the list other animals that you think should be protected. In each case give definite reasons why you think these animals should be protected.

3. Read in government bulletins and other references to find more about how experts learn the feeding habits of animals.

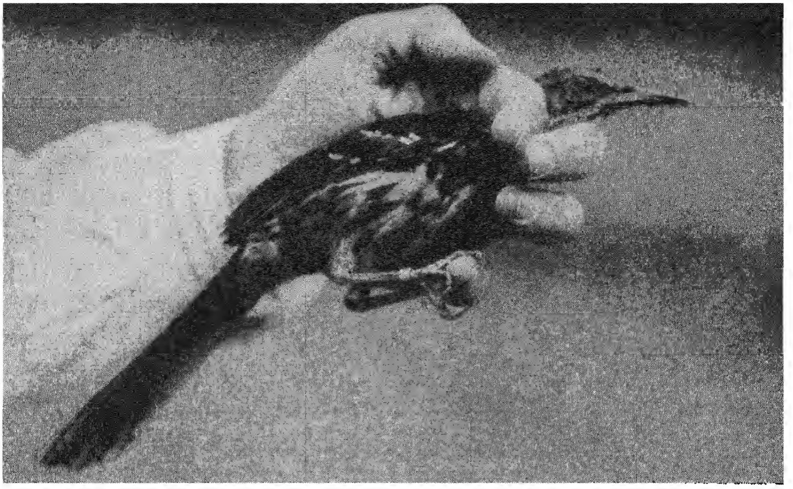


FIG. 594. A brown thrasher with a leg band. The picture shows how to hold a bird without frightening and injuring it. The fingers, held lightly around the neck, quiet it, the thumb (raised for the picture) rests on the wing to prevent fluttering, while the bird perches on the little finger. (U. S. Bureau of Biological Survey photo)

WHAT ARE SOME OF THE WAYS OF CONSERVING WILD ANIMALS? Have you ever heard of birds wearing "bracelets" like the one in Figure 594? For years the United States Government has operated bird-banding stations for the purpose of tracing the migration routes of birds. These birds are caught in harmless traps, and a band with a number on it is fastened around one leg. In government offices a record is kept of the kind of bird, when and where it was banded, and the number. When this bird is again captured, the number and date are reported.

In this way the migration routes and the dates of these journeys are learned, because bird-banding stations have been established in many parts of the world. Then bird sanctuaries are established in many places along the routes, especially along waterways (Figure 595). In these sanctuaries no one is allowed to kill the birds, and food and shelter are provided. Thus many birds that might be killed make their seasonal migration journeys safely.

FIG. 595. At the Blackwater Migratory Waterfowl Refuge in Maryland, mallards, black ducks, and many other ducks take advantage of the daily rations of grain. (U. S. Bureau of Biological Survey photo)

You, too, can help save birds and other animals. You can build bird homes and feeding stations, and you can help keep animal enemies, such as stray cats, in check. Scouts, bird clubs, and other organizations are of great help in carrying out this valuable work.

In a similar manner game preserves are set aside by the National and State Governments and by a few private organizations. Many of these places are operated in connection with state and national parks. Here trees and shrubs are planted for food and protection, and hunting and trapping are forbidden. The state of Maine, at least, is using the most modern methods in caring for the animals in such preserves. In some parts of that state the game wardens patrol their areas in planes. When the snow is deep and stays on the ground for long periods of time, sometimes large herds of deer and moose are unable to find food. Wardens in planes locate these herds easily, land their planes on skis, and chop down evergreens for food and make trails to places where food can be found. If it is impossible for planes to land, food is dropped to the animals. Trouble and expense? Yes, but this state

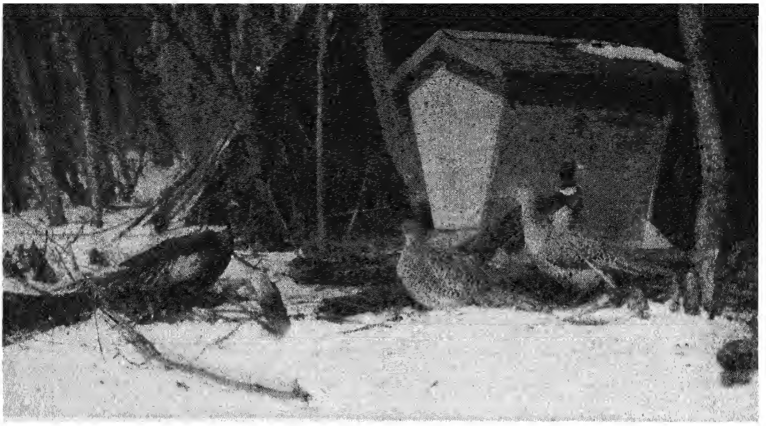


Fig. 596. In winter, when food is scarce, the foresters provide food for pheasants at feeding stations in a Wisconsin game refuge. (Wisconsin Conservation Department photo)

believes it is worth while. Farmers can follow the government's example in leaving trees and shrubs on their land (or planting them), thus providing food, breeding places, and shelter for large numbers of animals that would otherwise die. Often swampy places and streams are set aside as homes for beavers, muskrats, and other water animals. In these preserves no one is allowed to hunt or trap.

Did you ever hear of streams or lakes that are "fished out"? Fishing is great sport, and so many people enjoy it that our lakes and streams have become almost empty of fish. To restock such places and to stock places that do not have certain kinds of fish, national and state governments operate fish hatcheries all over our country. The men in charge of these hatcheries make surveys to find the best kinds of fish to put in different localities. They provide millions of fish from the hatcheries and help put them in places where they are needed.

Of course, many interesting problems arise in this work. The experts see to it that the correct number of fish are provided for the natural food supply. They may even suggest planting certain kinds of water plants for food, and they see that sewage, chemicals from factories along

streams, and other sources of pollution are eliminated. These would kill the fish, plants, and other wild life in such places. Recently the conservation workers have tried dropping fish into high mountain lakes from airplanes. This saves carrying cans of young fish up steep mountain sides on horses. Tests show that the fish are in better condition when dropped from planes than if they are carried up the mountain sides in cans.

In many parts of our country there are fur farms to provide furs for commercial use. Hunting and trapping have greatly cut down the number of fur-bearing animals. However, people still want furs. So, to meet the demand, fox farms, mink farms, and other animal farms have been established. They undoubtedly save many wild animals from destruction.

Other efforts to conserve animal life are the prevention of forest fires and the study of diseases of wild animals. Forest rangers with their fire towers and their forest patrols help in preventing forest fires. These fires not only kill or drive out wild life, but they destroy food and the natural homes of animals. Our national government

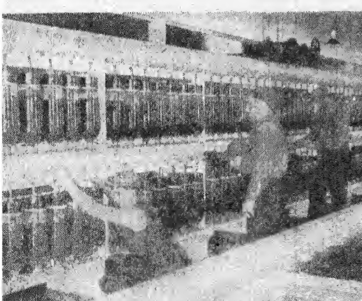


FIG. 597. Hatching jars, filled with muskellunge eggs (Wisconsin Conservation Dept. photos)

FIG. 598. Muskellunge *fry* (young fish) being planted in an area to which they are adapted

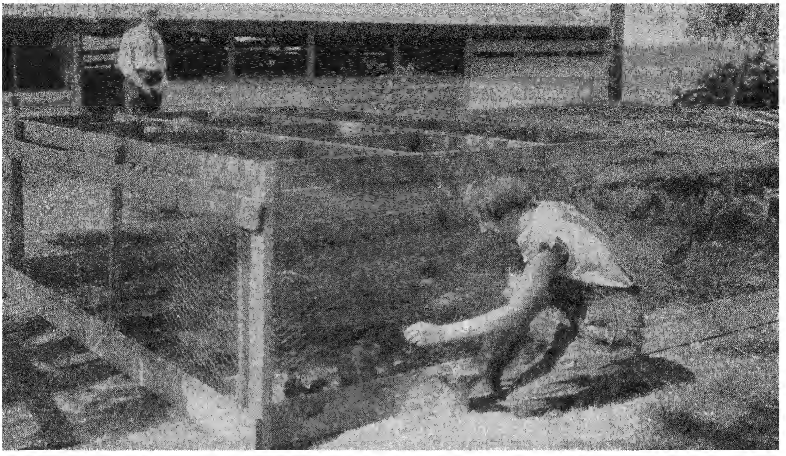


FIG. 599. Raising pheasants for the State Game Commission is a definite project of 4-H clubs in several states. (Bureau of Biological Survey photo)

has spent much time and money studying animal diseases and ways of preventing them. For example, in 1937, after much experimenting the United States Department of Agriculture printed a bulletin (*Farmers' Bulletin* No. 1781) telling about the diseases of upland game birds. This bulletin describes many bird diseases, such as tuberculosis, malaria, blackhead, and pneumonia. Did you know that birds have all of these and many other kinds of diseases? It also describes methods of fighting these diseases by proper feeding, by the use of chemicals, and in other ways.

Game laws are another means of protecting our wild life. These laws are carefully planned to prevent the killing of animals during the breeding season and to limit the number that can be killed by any person during one day or during the hunting season. By these laws we help conserve the supply of wild life so that there will be animals to hunt in the future. Hunting and fishing licenses are required in most places, and the money from these is used to pay game wardens and for other conserva-

tion purposes. Special licenses are issued to collectors of animal specimens for museums and other scientific institutions.

Probably one of the greatest needs of saving our wild animals is the development of good sportsmanship among people who love to hunt and fish. Hunters and fishermen should willingly buy their licenses, because the money is used for the sportsman's own good. Hunters should never kill or trap more game than the law allows, even though they may feel sure that they will not be caught by the game warden. Fishermen should obey the law regarding the number of fish they are allowed to catch, and they should put back into the water any fish that are under the size prescribed by the law. Finally, people who are to enjoy our wild life should be willing to coöperate in every way possible in trying to save our animals. These are but a few examples of the sportsman's code. Can you add any others? Are you a good sportsman?

Self-Testing Exercises

1. List as many different ways as you can of protecting wild life. Check with your book to see whether you have omitted any mentioned there. Give examples (from your own observations, if possible) to show how these ways work.

2. Which of the agencies mentioned in your book are operating to protect animals in your locality? Are there others not mentioned in the book? List them.

Problems to Solve

1. Make a map of your state or of the United States. Show by means of color where bird sanctuaries, game preserves, and other places for protection of animals are located.

2. Get a copy of the game laws in your state and study them carefully so that you will understand better what is being done to protect animal life.

Problem 4:

HOW CAN WE MAKE THE BEST USE OF OUR FORESTS?

Our forests provide lumber for building houses, cross-ties for railroad tracks, fence and telegraph poles, piling for bridges, and material for making barrels, boxes, crates, and furniture. In some parts of our country the forests furnish us with fuel. Resin, turpentine, and tannin are other valuable forest products. Even the paper on which this book is printed is made of wood pulp.

Notice in Table 7 what becomes of the wood in a typical tree that is cut for our use. Only a little over one-third of the material of the entire tree is available for use as lumber! Fortunately, however, not all of the other

TABLE 7. What Becomes of the Wood in a Tree

Left in stump, limbs, and top	18.9	per cent
Bark	10.5	" "
Sawdust	11	" "
Slabs from sides of logs	7.1	" "
Trimmings and edgings from boards	7.1	" "
Careless waste	2.8	" "
Weight lost in drying	5	" "
Seasoned, undressed lumber	37.6	" "

63 per cent is wasted. The increasing scarcity of wood has made us learn to use practically all of the tree. For example, the limbs are used for fuel, trees are being cut closer to the ground, leaving little waste as stumps, and sawdust is even being made into paper pulp. Another way of saving some kinds of wood is called *veneering*. Instead of making furniture and other articles of solid oak, walnut, or other scarce wood, rapidly revolving knives cut the wood into large sheets almost as thin as paper. These sheets are glued over cheaper wood, and

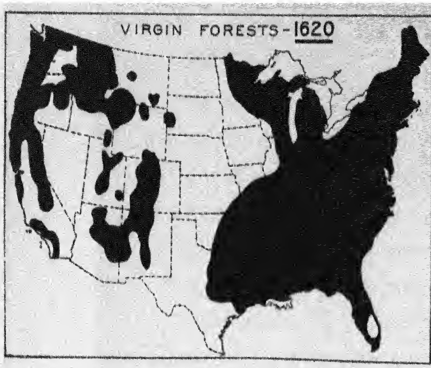


FIG. 600. When the colonists first came to this country, a little less than one-half of the land was covered with forests. (U. S. Forest Service photos)

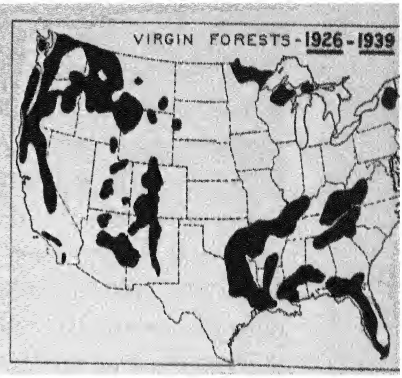


FIG. 601. In 1926 the total forest area was about sixty per cent of the original area. Today the forest area remains about the same as in 1926.

the result is a product that looks as well as solid oak or walnut. In this way valuable wood can be made to go farther than it otherwise would.

The problem of forest conservation is not a new one. As early as 1670 several towns in Massachusetts began to experience a shortage of lumber. Since then the shortage has become greater each year as more and more of our forests have been destroyed. A glance at Figures 600 and 601 will make this even clearer to you. In recent years the problem of how to save and protect our forests has become so important that our national government has established the United States Forest Service and other organizations to help solve the problem. Millions of acres have been bought by the government and set aside as National Forests. Most states have also established forestry commissions, and many excellent private organizations are helping in the fight. Your part as an intelligent citizen will be to learn what can be done in the way of forest con-

servation and what you yourself can do; for, after all, saving our forests is a problem for every individual as well as for organizations.

HOW CAN WE PROTECT THE FORESTS WE NOW HAVE? Fires do the greatest amount of damage to our forests, and over 90 per cent of these fires are started by the carelessness of people. Each year over 150,000 forest fires cause 75,000,000 dollars worth of damage to timber and other property in the United States. So one of the most important steps in saving our trees is the prevention of forest fires. Prevention of fires also saves many wild birds and mammals from being killed and preserves their homes. This important task of protection from fires is largely in the hands of forest wardens. These wardens are given the power to enforce forest laws and are provided with special fire-fighting equipment. Fire stations are well supplied with fire-rakes, chemical fire-extinguishers, and other equipment.

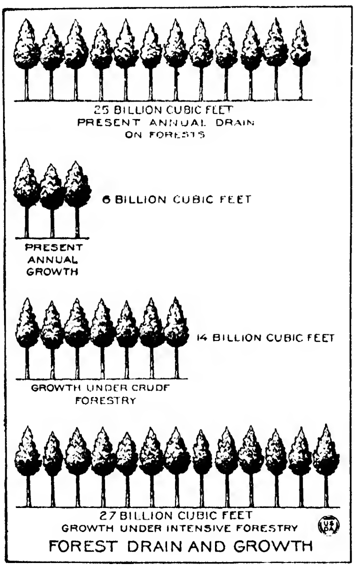


FIG. 602. This chart shows the need for intensive reforestation. (U. S. Forest Service)

To help discover and locate fires, "lookout towers" are built. In each tower is an observer with binoculars, maps, direction indicators, and other instruments. When a fire is discovered, a message giving its exact position is sent by telephone or radio down to headquarters in the valley. Fire-fighters then "get on the job" to stop the fire before it

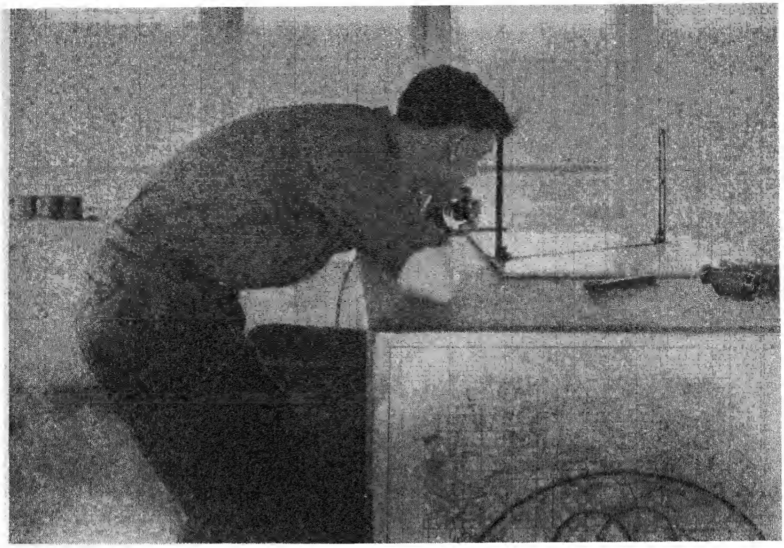


FIG. 603. The inside of a fire lookout station. When the lookout man sees smoke, he sights through a direction indicator and uses his maps to locate the fire exactly. (U. S. Forest Service photo)

spreads and gets out of control. Some fire-tower stations have sleeping and cooking quarters for the observers. Airplanes are used in some places for patrolling forests and finding forest fires. Planes fly regularly over their patrol regions, spot fires, and report them by means of radio.

But waiting until a fire starts and then trying to put it out is dangerous business. So, to help control fires, *fire lanes* are made. To make a fire lane the timber is cut from a narrow strip, and the ground is plowed through regularly. Thus if a fire starts in one part of a forest, it is prevented from spreading to other parts. In fighting fires that have started, water is pumped from streams and lakes. Chemical extinguishers are coming into use, and experts think these will aid greatly in reducing the fire losses in our forests. Many states require that railroads cut a fire strip one hundred yards wide on either side of the road-bed and clear all of the inflammable material from this strip.

Fig. 604. To cut trees so as to preserve the forest for many years is a scientific procedure. These foresters are marking the adult trees they have selected to be cut down. (U. S. Forest Service photo)

Forest conservation is being practiced in still another way. Formerly, every usable tree was cut from the land as the logging crew went about its work. But the increasing scarcity of timber has now led to *selective cutting.* By this plan only a certain number of trees are cut for use at any single time. Other trees are left to mature, and new ones are planted as the supply is used. This keeps a steady supply of trees growing, and, if it is practiced widely enough, we may be sure of having lumber in the future. Forestry specialists have learned that selective cutting not only keeps a reserve supply of trees, but it makes these trees grow faster. Thinning trees gives them room to grow, just as thinning field crops does.

Another way of protecting our forests is the study of tree diseases. Have you ever stopped to think how much trees are like people? In any large forest there are great numbers of healthy trees, just as in any large group of people there are many healthy people. However, there are always people who are sick. It is the same way in a forest;

there are always trees that are diseased, weakened from old age, or injured. Trees suffer from disease epidemics just as people do. For example, about fifty years ago people began to plant nut trees that were imported from the Orient. With these trees came a disease known as the *chestnut blight*.

People paid little attention to this disease until most of the chestnut forests in Virginia, West Virginia, North Carolina, Pennsylvania, New Jersey, New York, Connecticut, Massachusetts, and other states were infected. The government became alarmed at the rapid loss of these valuable trees and began experimenting to find ways of fighting the disease. However, they had waited too long to start the fight, and as a result practically all of our chestnut forests are gone. Experiments are still being made to find a kind of chestnut that will resist this blight.

Other diseases that are becoming widespread are *white-pine blister rust* and the *Dutch elm disease*. These diseases threaten to destroy much of our white pine, which is so valuable as a source of lumber, and our stately elms, which are valued for their beauty. So far no cure has been found, but in recent years the government has spent about $1,500,000 each year in trying to control these diseases. Still other diseases, such as *beech-bark fungus*, *willow*

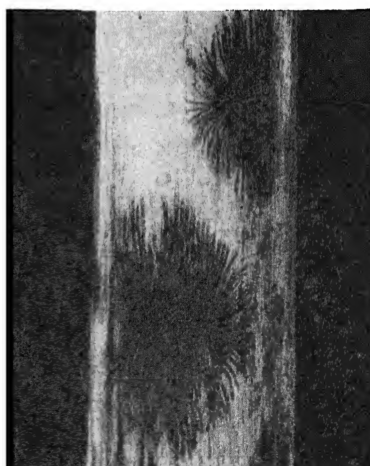


FIG. 605. Tunnels made in an elm by beetles that carry the Dutch elm disease (N.Y. Botanic Garden-American Forestry Association)

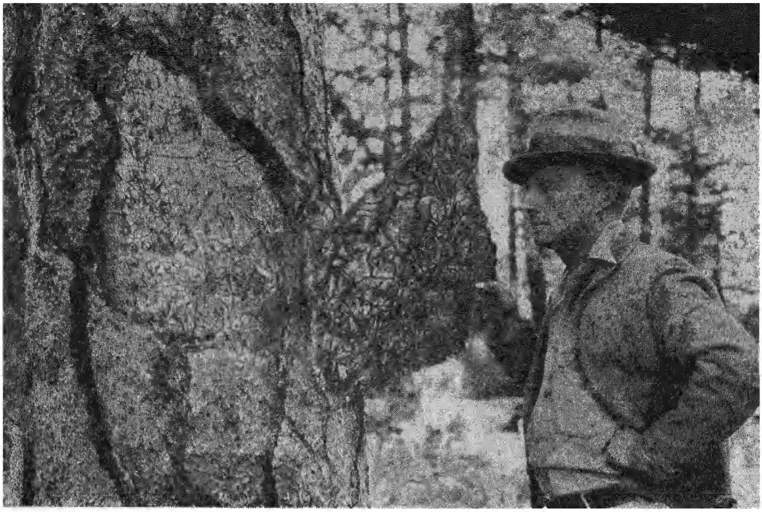


FIG. 606. The destructive work of the pine blister beetle in a white pine (U. S. Forest Service photo)

blight, and others, also threaten our forests. In addition to these, insects take their toll from our forests. Much is being done toward finding ways of controlling or curing tree diseases and getting rid of insect pests. The job is a big one, and about the only way of getting results seems to be by experimenting to find ways of controlling forest enemies of this kind and educating people to do their part in the fight.

Self-Testing Exercises

1. List methods of fighting forest fires. Try to add to your list other ways than those mentioned in your book.
2. What is selective cutting of trees? How does it work?
3. Do you think the government is justified in spending large amounts of money each year in the study and control of diseases of forest trees and of insect pests? Why?

Problems to Solve

1. Find in newspapers and recent scientific magazines reports of (*a*) new uses for wood, and (*b*) substitutes that have been found for wood.
2. Make a list of national, state, and private organizations

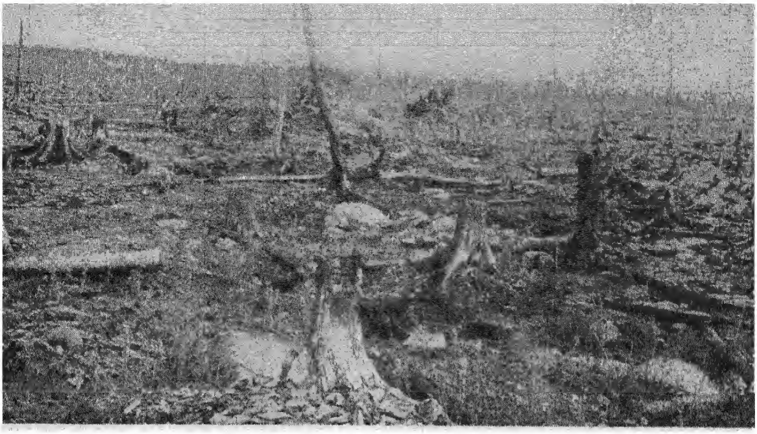


Fig. 607. We have in the United States millions of such desolate acres as these because the forest growth has been stripped by lumbering and by fires. Since such land cannot reseed itself, we must reforest it. (U. S. Forest Service photo)

that can be called on for aid in protecting our forests. After the name of each agency, try to list the kinds of help they offer.

3. Get a copy of the fire laws in regard to the forests of your state. Study them to see how you can help carry them out.

4. Find out what diseases and insects are damaging trees in your locality. What measures are being taken to control them?

How can we replace the forests that have been destroyed? Any successful factory must be studied constantly to see that each part of it is doing its share. Men and machinery cannot be idle in different parts of the plant if it is to be a success. If much of the land of our country lies idle when there is an increasing scarcity of forests, what should we expect? In a recent year 50,000,000 acres of land in the United States lay idle because the trees had been destroyed and poor methods of farming had made the land unfit for use. This land could be reforested and made productive if the correct methods were used. In most places people do not know how to go about reforestation because the idea is so new. What are some of the steps to be undertaken in doing this?

FIG. 608. Seed beds of one-year-old pines (Wisconsin Conservation Department photo)

One of the most important things to study is the quality of soil. The soil must be analyzed to find what kinds of trees will grow best in the places where they are to be planted. For example, yellow poplar, white oak, sugar maple, and white ash grow best in fairly rich moist loam and in clay-loam soils. Red pine, loblolly pine, and short-leaf pine grow best in dry sandy soils. Black locust and white pine thrive in moist and sandy-loam soils. Sweet gum, southern white cedar, and cypress grow best in semi-swampy soils. Very often mixed plantings are desirable. In this case the proper combinations must be made according to the locality and the type of soil.

Another thing to be considered is the size of seedlings to be planted. Most experiments show that no tree under six inches in height (not including the root system) should be planted. Other experiments show that reforestation projects are more successful when nursery stock rather than native seedlings is used. Young trees may be bought by the thousand very cheaply in most places.

Then comes the preparation of the land. Strangely enough, in most places scattered shrubby growth and older trees of poor quality should be removed before the new stock is planted. Planting may be done in the spring or fall, depending upon seasonal conditions, of course. The seedlings may be planted in furrows that have been broken with plows or in holes that are made with special tools. In some places they are planted in squares, and in others they are staggered. A good spacing is six feet in all directions from other seedlings.

Experts say that the most damage to seedlings is done between the time they are taken from the nursery and the time they are planted. The tender root-hairs dry out and die, making it hard for the young trees to get a start. The seedlings should be "heeled-in" (put in trenches and covered with very moist soil) until they are put in their permanent places. Another caution experts give is in regard to the depth of planting. In general, seedlings should be planted about one-half inch deeper than they grew in the nursery. The roots should be spread out in a normal position, but should never be curved upward. Finally, the soil must be packed tightly to fill up air pockets that might have been left about the roots. Then the trees are ready to do their part in the reforestation project.

Fortunately, little care of the young forest is necessary. About all that must be done is to keep out large plants (such as weeds and shrubs) that would shade the small trees. Of course, insect damage and forest fires must be prevented, if possible, just as they would in any other forest. Trees are a paying crop in the long run, especially when they can be grown on land that is not well suited to other kinds of crops. In some places Christmas-tree farming pays well.

FIG. 609. Before a woodsman builds a camp fire, he clears a place of all grass, pine needles, and trash, digs a hole, and in it builds the fire. (U. S. Forest Service photos)

FIG. 610. Before leaving a camp fire, even for a short time, one should first pour plenty of water over it and then cover it with earth.

The national and state governments and other agencies are doing so much for you and other citizens in restoring our forests, establishing natural parks and camping grounds, maintaining fire patrols, and providing museum exhibits of forest products. What can you do to help? You have already been doing something very important. You have been learning about conservation. The next step is to put what you have learned into practice in so far as you are able. When you take hikes and cook meals in the woods, you can prevent fires by obeying the fire laws and by seeing that others obey them. You can help plant trees where they are needed, and you can keep informed about what is happening to our forests. You can insist that our state and national law-makers vote right on laws that we need to save our forests.

Self-Testing Exercise

Make a list of important things to know in planning to plant trees on a large scale.

Problems to Solve

1. Talk with farmers, lumbermen, and other people in your community to find out (*a*) what kinds of trees are considered of most value, (*b*) which are of least value, (*c*) which are most plentiful, (*d*) which are scarce, and (*e*) what kinds of trees grow best.

2. Are any reforestation projects being carried on near you? If so, visit them to find out what methods are being used. Note carefully the kinds of trees that are being planted, when the planting is done, the spacing of seedlings, the depth of planting, and other important factors.

3. Get a map of your community and make a survey to find where tree planting should be done. Color these places in a special way on your map. This is a good class project.

4. What additions or corrections would you make in answering Exercise 9 of the *Introductory Exercises* now? Add these to your original answer.

LOOKING BACK AT UNIT 12

1. Copy the sub-problems of this unit, and write a few sentences to answer the main question asked in each sub-problem. If several ways of solving a particular problem are given, list these ways. This exercise is planned to give you a picture of conservation as it is discussed in this unit.

2. Show in any way which seems best to you that you know the meanings of the following words or terms:

contour farming	*strip cropping*	*selective cutting*
bituminous coal	*cracking oil*	*lignite*
re-pressuring	*terracing*	*fuel oil*
clean farming	*good sportsmanship*	*anthracite coal*

ADDITIONAL EXERCISES

1. Make a collection of the wood of different kinds of trees that grow in your locality and elsewhere. Cut the specimens in four-by-six-inch sizes and sandpaper them to bring out the natural grain of the wood. Mount them for display in your

classroom or school museum. Be sure to label each specimen carefully.

2. Make a large graph to show what becomes of the wood from an average tree that is used for lumber. Use the figures given on page 700.

3. Write to the United States Department of Agriculture, your State Department of Agriculture, and other sources for lists of bulletins and free material on conservation. Secure as many different kinds of these as possible for your school library. They will help you in any further work you want to do on conservation.

4. Make a collection of coal and products that are made from coal. Do the same for petroleum. Mount these products so that they may be used for study in class.

5. Make plans for a bird shelter and feeding station. State what kinds of birds you would expect to use it.

6. With your classmates visit your schoolground, a near-by park, or a woodland and plan a bird sanctuary. Make a map of the place and locate the best places to put bird houses, feeding stations, and for planting wild plants to be used as food by the birds. If possible, put your plan into action by proposing it to the Boy Scouts, Girl Scouts, or other organizations to which you belong. Ask your teacher, your scoutmaster, and your parents to help with your project.

7. How is the study of animal diseases a part of conservation? Write for *Farmers' Bulletin No. 1781*, United States Department of Agriculture, and read it to find the answer to the problem.

8. Make a special study of the conservation of wild flowers. What is being done in your own state? Write to the Wild Flower Preservation Society, 3740 Oliver Street, Washington, D. C., for information.

READINGS IN SCIENCE

This part of the book is to help you find interesting science reading outside your textbook. The *General Books* named below are books that have parts on a great many different scientific topics. Usually you can find what you want to read by looking for a topic or word in its alphabetical place or in the index.

On this page there is a list of magazines that may interest you. Beginning on page 714 are the *Books on Special Topics*. These books are of many different kinds. Some of them are interesting to read all the way through. Some of these books will be most useful when you want to find out more about some special topic for your own satisfaction and for reports to your class.

I. GENERAL BOOKS

Book of Knowledge (20 volumes). Grolier Society, 1931.
Book of Popular Science (16 volumes). Grolier Society, 1931.
Boy Scouts of America. The Official Scout Handbook for Boys, 1935.
Compton's Pictured Encyclopedia (15 volumes). Compton, 1937.
Girl Scouts of America. The Official Scout Handbook for Girls, 1933.
World Book Encyclopedia (13 volumes). W. F. Quarrie and Co., 1934.

II. MAGAZINES

Current Science, Am. Education Press, 400 S. Front St., Columbus, O.
Junior Natural History, American Museum of Natural History, Central Park West at 79th St., New York, N. Y.
Junior Scholastic, Chamber of Commerce Building, Pittsburgh, Pa.
National Geographic Magazine, Washington, D. C.
Nature Magazine, 1214 Sixteenth St., N. W., Washington, D. C.
Popular Mechanics, 200 E. Ontario St., Chicago, Ill.
Popular Science Monthly, 381 Fourth Ave., New York, N. Y.
Science Digest, 631 St. Clair St., Chicago, Ill.
Science News Letter, 2101 Constitution Ave., Washington, D. C.
Scientific American, 24 W. 40th St., New York, N. Y.

III. BOOKS ON SPECIAL TOPICS

Unit 1: How Do Living Things Behave?

ALLEN, A. *American Bird Biographies*. Comstock, 1934.
BAKER, A. O., AND MILLS, L. H. *Dynamic Biology* (pages 523-568). Rand, 1938.
BEEBE, WILLIAM. *Exploring with Beebe*. Putnam, 1932.
CHAPMAN, F. M. *The Travels of Birds*. Appleton-Century, 1916.
CURTIS, BRIAN. *Life Story of the Fish* (pages 70-125, 181-259). Appleton-Century, 1938.
DAGLISH, E. *Marvels of Plant Life* (pages 49-100). Butterworth, 1929.
DITMARS, R. *Book of Insect Oddities*. Lippincott, 1938.
EALAND, C. A. *The Marvels of Animal Ingenuity* (pages 178-188). Lippincott, 1926.
EMERSON, A. E., AND FISH, E. *Termite City*. Rand, 1937.
FINLEY, W. L. *Wild Animal Pets*. Scribners, 1928.
FLINT, W. *Insects, Man's Chief Competitor* (pp. 84-133). Williams, 1932.
HORNADAY, W. T. *Tales from Nature's Wonderland* (pages 93-235). Scribners, 1924.
HOWARD, L. *The Insect Menace* (pp. 81-101). Appleton-Century, 1931.
HUXLEY, J. S. *Simple Science* (pages 234-278). Harper, 1935.
MAETERLINCK, MAURICE. *Life of the Bee*. Dodd, 1913.
MELLEN, I. M. *Young Folks' Book of Fishes*. Dodd, 1927.
PICKWELL, GAYLE. *Birds* (pages 24-79, 88-99, 114-125, 132-154, 216-222). McGraw, 1939.
RUSSELL, E. S. *The Behavior of Animals*. Longmans, 1938.
VERRILL, A. H. *Strange Insects and Their Stories*. Page, 1937.
WEED, C. M. *Insect Ways*. Appleton-Century, 1930.

Unit 2: How Do Scientists Classify Living Things?

ANTHONY, H. *Fieldbook of North American Mammals*. Putnam, 1928.
BAKER, A. O., AND MILLS, L. H. *Dynamic Biology* (pages 295-482). Rand, 1938.
BLANCHAN, NELTJE. *The Bird Book*. Doubleday, 1932.
BRADLEY, J. C. *Insect Life*. Boy Scouts of America, 1931.
BUCHSBAUM, RALPH. *Animals Without Backbones*. University of Chicago Press, 1938.
DITMARS, R., AND CARTER, H. *Book of Living Reptiles*. Lippincott, 1938.
EIFRIG, C. W. *Reptiles, Amphibians, and Fishes*. Rand, 1930.
FEDERAL WRITERS' PROJECT. *Who's Who in the Zoo*. Halcyon, 1937.
FULLER, R. T. *Along the Brook*. Reynal, 1931.
GAGER, C. S. *The Plant World*. University Society, 1931.

HEGNER, R. W. *Parade of the Animal Kingdom.* Macmillan, 1935.
HOLLAND, W. J. *The Butterfly Book.* Doubleday, 1931.
HYLANDER, C. J. *American Scientists* (pages 29-43, 53-64, 123-130). Macmillan, 1935.
HYLANDER, C. J. *The Year Round.* Putnam, 1932.
LUTZ, F. E. *Field Book of Insects.* Putnam, 1935.
MATHEWS, F. *Book of Wild Flowers for Young People.* Putnam, 1923.
MORGAN, A. H. *Field Book of Ponds and Streams.* Putnam, 1930.
PETERSON, R. T. *A Field Guide to the Birds.* Houghton, 1934.
POPE, C. *Snakes Alive and How They Live* (pp. 174-226). Viking, 1937.
ROGERS, JULIA E. *Tree Book.* Doubleday, 1914.
TEALE, EDWIN W. *The Boys' Book of Insects.* Dutton, 1939.

Unit 3: How Are Plants and Animals Fitted to the Conditions Around Them?

BAKER, A. O., AND MILLS, L. H. *Dynamic Biology* (pages 1-55, 502-518). Rand, 1938.
BEEBE, WILLIAM. *Nonsuch: Land of Water* (pages 17-32, 77-93, 185-237). Harcourt, 1932.
CURTIS, BRIAN. *Life Story of the Fish* (pages 126-143, 230-234). Appleton-Century, 1938.
EALAND, C. A. *The Marvels of Animal Ingenuity* (pages 79-91, 201-226). Lippincott, 1926.
FABRE, JEAN-HENRI. *Marvels of the Insect World.* Appleton-Century, 1938.
HOWARD, L. *The Insect Menace* (pp. 18-136). Appleton-Century, 1931.
KEARNEY, P. *Strange Fishes and Their Strange Neighbors.* Doubleday, 1933.
KENLY, JULIE C. *Cities of Wax.* Appleton-Century, 1935.
MCCLINTOCK, THEODORE. *Underwater Zoo.* Vanguard, 1938.
MORGAN, A. *An Aquarium Book for Boys and Girls.* Scribners, 1936.
PICKWELL, GAYLE. *Birds* (pages 24-154, 216-222). McGraw, 1939.
PICKWELL, GAYLE. *Deserts* (pages 43-163). McGraw, 1939.
POPE, C. H. *Snakes Alive and How They Live.* Viking, 1937.
QUINN, VERNON. *Leaves, Their Place in Life and Legend.* Stokes, 1937.
QUINN, VERNON. *Roots, Their Place in Life and Legend.* Stokes, 1938.
SANDERSON, IVAN. *Animal Treasure.* Viking, 1937.
VERRILL, A. H. *Strange Animals and Their Stories.* Page, 1939.
VERRILL, A. H. *Strange Fish and Their Stories.* Page, 1938.
VERRILL, A. H. *Strange Insects and Their Stories.* Page, 1937.
VERRILL, A. H. *Wonder Plants and Plant Wonders.* Appleton-Century, 1939.

Unit 4: How Do Simple Machines Help Us Do Work?

BOCK, G. E. *What Makes the Wheels Go 'Round?* (pages 1-18). Macmillan, 1931.

BOWDEN, G. A. *Foundations of Science* (pages 327-350). Blakiston, 1931.

COLLINS, A. F. *Experimental Mechanics.* Appleton-Century, 1931.

DAVIS, LAVINIA R. *Adventures in Steel.* Modern Age, 1938.

DULL, C. E. *Modern Physics* (pages 217-247). Holt, 1929.

HAWKS, ELLISON. *Boys' Book of Remarkable Machinery* (pages 131-289). Dodd, 1937.

HYLANDER, C. J. *American Inventors* (pages 27-34, 59-72, 109-116). Macmillan, 1934.

MEISTER, MORRIS. *Living in a World of Science: Energy and Power* (pages 120-166). Scribners, 1935.

MORGAN, ALFRED P. *Boys' Home Book of Science and Construction* (pages 73-122). Lothrop, 1921.

WILSON, GROVE. *Great Men of Science, Their Lives and Discoveries* (pages 43-52). Garden City, 1932.

Unit 5: How Do We Make Electrical Currents?

BOLTON, S. K. *Famous Men of Science* (pages 164-172). Crowell, 1938.

COLLINS, A. F. *How to Understand Electricity.* Lippincott, 1935.

FRANKLIN, BENJAMIN. *Autobiography.* Houghton, 1923.

HAWKS, ELLISON. *The Book of Electrical Wonders* (pages 19-51). Dial Press, 1931.

HUXLEY, J. S. *Simple Science* (pages 421-457). Harper, 1935.

HYLANDER, C. *American Scientists* (pp. 1-10, 44-52). Macmillan, 1935.

LUNT, J. R. *Everyday Electricity* (pages 1-45, 74-90). Macmillan, 1927.

MEISTER, MORRIS. *Living in a World of Science: Magnetism and Electricity* (pages 43-95). Scribners, 1929.

MORGAN, A. P. *A First Electrical Book for Boys* (pages 1-64, 142-151). Scribners, 1935.

MORGAN, A. P. *Boys' Home Book of Science and Construction* (pages 310-340). Lothrop, 1921.

PARKER, B. *The Book of Electricity* (pp. 1-58, 82-87). Houghton, 1928.

SIMONDS, WM. A. *A Boy with Edison* (pages 88-100). Doubleday, 1931.

WILLIAMS-ELLIS, AMABEL. *Men Who Found Out* (pages 109-129). Coward, 1930.

WILSON, G. *Great Men of Science* (pages 249-274). Garden City, 1932.

Unit 6: How Do We Use Sound?

BLACK, N. H., AND DAVIS, H. N. *New Practical Physics* (pages 451-489). Macmillan, 1929.

BRAGG, SIR WILLIAM. *The World of Sound.* Dutton, 1920.

Cottler, J., and Jaffe, H. *Heroes of Science* (pages 22-41). Little, 1932.
Dull, C. E. *Modern Physics* (pages 356-400). Holt, 1929.
Jeans, James. *Science and Music*. Macmillan, 1938.
Meadowcroft, W. H. *The Boy's Life of Edison* (pages 175-182). Harper, 1921.
Meister, Morris. *Living in a World of Science: Water and Air* (pages 182-230). Scribners, 1930.
Miller, F. T. *Thomas A. Edison* (pages 166-189). Winston, 1931.
Morgan, A. P. *Boys' Home Book of Science and Construction* (pages 174-204). Lothrop, 1921.
Schwartz, H. W. *The Story of Musical Instruments from Shepherd's Pipe to Symphony*. Doubleday, 1938.
Wilson, S. R. *Descriptive Physics* (pages 17-32). Holt, 1936.

Unit 7: How Do We Use Light Energy?

Baker, A. O., and Mills, L. H. *Dynamic Biology* (pages 63-73). Rand, 1938.
Black, N. H., and Davis, H. N. *New Practical Physics* (pages 492-567). Macmillan, 1929.
Bowden, G. *Foundations of Science* (pp. 267-321). Blakiston, 1931.
Collins, A. F. *Experimental Optics*. Appleton-Century, 1933.
De Kruif, P. *Men Against Death* (pages 283-331). Harcourt, 1932.
Dull, C. E. *Modern Physics* (pages 404-498). Holt, 1929.
Eaton, Jeanette. *The Story of Light*. Harper, 1928.
Furnas, C. C. *The Next Hundred Years* (pp. 231-277). Reynal, 1936.
Huxley, J. S. *Simple Science* (pages 534-574). Harper, 1935.
Hylander, C. *American Inventors* (pages 174-184). Macmillan, 1934.
Hylander, C. *American Scientists* (pages 156-160). Macmillan, 1935.
Johnson, G. *Hunting with the Microscope*. Leisure League, 1936.
Meister, Morris. *Living in a World of Science: Energy and Power* (pages 13-105, 234-238). Scribners, 1935.
Morgan, A. P. *Boys' Home Book of Science and Construction* (pages 256-309). Lothrop, 1921.
Neblette, C. B., Boehm, F. W., and Priest, E. L. *Elementary Photography*. Macmillan, 1936.
Wilson, S. R. *Descriptive Physics* (pages 34-61). Holt, 1936.

Unit 8: How Do We Use Electrical Current?

Black, N. H., and Davis, H. N. *New Practical Physics* (pages 568-592). Macmillan, 1929.
Bolton, S. K. *Famous Men of Science* (pages 334-348, 363-376). Crowell, 1938.

Collins, A. F. *Book of Wireless Telegraph and Telephone.* Appleton-Century, 1936.
Collins, A. F. *Fun with Electricity.* Appleton-Century, 1936.
Cook, S. *Things to Make with Dry Cells.* Burgess Battery Co., 1938.
Floherty, J. J. *On the Air: The Story of Radio.* Doubleday, 1937.
Hammond, J. W. *A Magician of Science; the Boys' Life of Steinmetz.* Appleton-Century, 1926.
Hawks, Ellison. *The Book of Electrical Wonders* (pages 82-312). Dial Press, 1931.
Headquarters Staff of American Radio Relay League. *Radio Amateur's Handbook.*
Hylander, C. J. *American Inventors* (pages 73-85, 126-139, 147-173, 185-198). Macmillan, 1934.
Lambert, Clara. *Talking Wires.* Macmillan, 1935.
Lunt, J. *Everyday Electricity* (pp. 46-73, 109-286). Macmillan, 1927.
Meister, Morris. *Living in a World of Science: Magnetism and Electricity* (pages 31-42, 96-212). Scribners, 1929.
Miller, F. T. *Thomas A. Edison.* Winston, 1931.
Morgan, A. P. *A First Electrical Book for Boys* (pages 65-141, 153-206). Scribners, 1935.
Morgan, A. P. *Things a Boy Can Do with Electricity.* Scribners, 1938.
Moseley, S. A., and McKay, H. *Television: A Guide for the Amateur.* Oxford University Press, 1936.
Nicolay, Helen. *Wizard of the Wires.* Appleton-Century, 1938.
Parker, B. M. *The Book of Electricity* (pages 58-82, 123-309). Houghton, 1928.
Wilson, G. *Great Men of Science* (pages 346-357). Garden City, 1932.
Yates, R. F. *How to Make Electric Toys.* Appleton-Century, 1937.
Yates, R. F. *These Amazing Electrons.* Macmillan, 1937.

Unit 9: How Do We Harness the Energy of Nature to Do Our Work?

Abbott, C. G. *Utilizing Heat from the Sun.* Smithsonian Institute.
Andrade, E. N. *Engines* (pages 1-228, 256-264). Harcourt, 1928.
Bock, G. E. *What Makes the Wheels Go 'Round?* (pages 18-76). Macmillan, 1931.
Bowden, G. *Foundations of Science* (pp. 351-375). Blakiston, 1931.
Coolidge, A., and di Bona, A. *The Story of Steam.* Winston, 1935.
Diggle, E. G. *The Romance of a Modern Liner.* Oxford, 1930.
Furnas, C. C. *The Next Hundred Years* (pp. 199-230). Reynal, 1936.
Glover, K. *America Begins Again* (pages 231-255). McGraw, 1939.
Hawks, E. *Boys' Book of Remarkable Machinery* (pp. 1-130). Dodd, 1937.
Hawks, E. *The Book of Electrical Wonders* (pp. 52-81). Dial Press, 1931.

HODGINS, E., AND MAGOUN, F. A. *Behemoth, the Story of Power.* Doubleday, 1932.
HUXLEY, J. S. *Simple Science* (pages 95-102). Harper, 1935.
HYLANDER, C. J. *American Inventors* (pages 11-26, 35-58, 86-95, 117-125). Macmillan, 1934.
LUNT, J. R. *Everyday Electricity* (pages 91-108). Macmillan, 1927.
MEISTER, MORRIS. *Living in a World of Science: Energy and Power* (pages 120-130, 167-233). Scribners, 1935.
RECK, F. M. *Automobiles from Start to Finish.* Crowell, 1935.
REED, BRIAN. *Railway Engines of the World.* Oxford Press, 1934.
TYLER, D. B. *Steam Conquers the Atlantic.* Appleton-Century, 1939.
VERRILL, A. H. *Gasoline-Engine Book for Boys.* Harper, 1930.
WILSON, G. *Great Men of Science* (pages 358-366). Garden City, 1932.
WITTICK, E. C. *The Development of Power.* University of Chicago Press, 1939.
YATES, R. F. *Machines over Men.* Stokes, 1939.

Unit 10: How Do We Improve Plants and Animals?

ALTENBERG, E. *How We Inherit.* Holt, 1928.
BAKER, A. O., AND MILLS, L. H. *Dynamic Biology* (pages 625-656). Rand, 1938.
COTTLER, J., AND JAFFE, H. *Heroes of Science* (pages 181-189). Little, 1932.
DE KRUIF, P. *Hunger Fighters* (pages 3-68, 169-232). Harcourt, 1928.
DOWNING, E. R. *Elementary Eugenics.* Univ. of Chicago Press, 1928.
FURNAS, C. C. *The Next Hundred Years* (pages 7-21). Reynal, 1936.
HARWOOD, W. S. *New Creations in Plant Life.* Macmillan, 1927.
HUXLEY, J. S. *More Simple Science* (pages 254-295). Harper, 1936.
HYLANDER, C. *American Scientists* (pages 106-122). Macmillan, 1935.
JEWETT, FRANCES G. *The Next Generation.* Ginn, 1928.
U. S. Department of Agriculture Yearbook of Agriculture (1936—pages 119-1141; 1937—pages 119-1497). Good examples for this unit.
WILSON, G. *Great Men of Science* (pages 334-345). Garden City, 1932.

Unit 11: How Have Living Things Developed on the Earth?

BAKER, A. O., AND MILLS, L. H. *Dynamic Biology* (pages 661-682). Rand, 1938.
COTTLER, J., AND JAFFE, H. *Heroes of Science* (pages 170-180). Little, 1932.
DITMARS, R. L. *The Book of Zoography.* Lippincott, 1934.
FENTON, C. L. *Life Long Ago: The Story of Fossils.* Reynal, 1937.
FENTON, C. L. *Our Amazing Earth* (pages 245-333). Doubleday, 1938.
HORNADAY, W. T. *Tales from Nature's Wonderlands* (pages 1-92). Scribners, 1924.

Hotchkiss, W. O. *The Story of a Billion Years* (pages 1-99, 116-125). Williams, 1932.

Johnson, Gaylord. *How Father Time Changes the Animals' Shapes.* Messner, 1939.

Lucas, F. A. *Animals of the Past.* American Museum, 1929.

Lucas, J. M. *The Earth Changes.* Lippincott, 1937.

Lull, R. S. *Fossils.* University Society, 1931.

Noé, Adolf Carl. *Ferns, Fossils, and Fuel.* Follett, 1931.

Reed, W. M. *The Earth for Sam.* Harcourt, 1930.

Reed, W. M., and Lucas, J. M. *Animals on the March.* Harcourt, 1937.

Robinson, W. W. *Beasts of the Tar Pits.* Macmillan, 1932.

Schmidt, K. P. *Our Friendly Animals and Whence They Came.* Donohue, 1938.

Washburne, Carleton and Heluiz, and Reed, F. *The Story of Earth and Sky* (pages 26-89, 303-361). Appleton-Century, 1935.

Whitnall, Harold O. *A Parade of Ancient Animals.* Crowell, 1936.

Williams-Ellis, A. *Men Who Found Out* (pp. 130-154). Coward, 1930.

Wilson, Grove. *Great Men of Science* (pages 234-248, 306-333). Garden City, 1932.

Unit 12: How Can Science Help Us Keep from Wasting Nature's Wealth?

Bruère, M. B. *Taming Our Forests.* U. S. Dept. of Agriculture, 1938.

Butler, O. M. *American Conservation in Pictures and Story.* American Forestry Assn., 1935.

Chase, Stuart. *Rich Land, Poor Land.* McGraw, 1936.

Commons, Mrs. Marie A. *The Log of Tanager Hill.* Williams, 1938.

Curie, Eve. *Madame Curie, a Biography.* Doubleday, 1937.

Dahlberg, E. M. *Conservation of Renewable Resources.* C. C. Nelson, 1939.

Glover, K. *America Begins Again.* McGraw, 1939.

Hotchkiss, W. O. *The Story of a Billion Years* (pages 100-115, 126-137). Williams, 1932.

Howard, L. O. *The Insect Menace* (pages 137-342). Appleton-Century, 1931.

Lord, R. *To Hold This Soil.* Government Printing Office, 1938.

Pack, C. L., and Gill, Tom. *Forests and Mankind.* Macmillan, 1929.

Pack, C. L., and Gill, Tom. *Forest Facts for Schools.* Macmillan, 1931.

Rohan, B. J. *Our Forests, A National Problem.* C. C. Nelson, 1929.

Sears, P. B. *Deserts on the March.* Univ. of Oklahoma Press, 1935.

Sharpe, C. F. S. *What Is Soil Erosion?* Govt. Printing Office, 1938.

Worthen, E. L. *Farm Soils, Their Management and Fertilization.* Wiley, 1935.

SCIENCE WORDS

HERE is a list of the important science words in this book, with the pronunciation and the meaning of each one. The marked letters in parentheses are sounded according to the letters in the following list of sample words. The accented syllable is marked **′**. This lighter mark ′ shows a lighter accent.

a	hat, cap	ėr	term, learn	oi	oil, voice
ā	age, face	i	it, pin	ou	house, out
ã	care, air	ī	ice, five	u	cup, butter
ä	father, far	o	hot, rock	u̇	full, put
e	let, best	ō	open, go	ü	rule, move
ē	equal, see	ô	order, all	ū	use, music

ə represents *a* in about, *e* in taken, *i* in pencil, *o* in lemon, *u* in circus.

a cous ti cal (ə küs′ti kəl) **engineer,** a person who plans the control of sounds in buildings, etc.

Ac ri di dae (ak ri dī′dē), a family of insects that includes locusts and grasshoppers.

ad ap ta tion (ad′ap tā′shən), a structure or a method of behavior that makes living things fit their surroundings.

aer i al (ãr′i əl), the wires in the air for receiving and sending radio waves.

air bladder, a sac-like structure in fishes or plants for floating.

al gae, singular **al ga** (al′jē, al′gə), green plants that belong to the thallophyte group.

alternating current, an electric current that flows back and forth in a conductor instead of flowing always in the same direction.

am me ter (am′mē′tər or am′i tėr), an instrument that measures the strength of electric currents in amperes.

am pere (am′pēr), the unit for measuring the rate at which an electric current flows through a wire.

am phib i an (am fib′i ən), an animal living both on land and in water.
an gi o sperm (an′ji ō spėrm′), a plant that has its seeds enclosed in an ovary.
An nel i da (ə nel′i də), a group of invertebrate animals including earthworms and leeches.
a nus (ā′nəs), the opening at the end of the intestine through which waste material and undigested food pass.
A rach ni da (ə rak′ni də), a class of arthropods including spiders, scorpions, etc.
arc lamp, a lamp in which an electric arc is the source of light.
ar ma ture (är′mə chər), 1. the piece of soft iron arranged to be attracted by the poles of a magnet. 2. the coils of wire that revolve in the magnetic field of a generator to produce electric current. 3. the revolving part of an electric motor.
Ar throp o da (är throp′ə də), a group of animals whose legs and other appendages are jointed, including the insects, crayfish, etc.
as so ci a tion (ə sō′si ā′shən), the connection of ideas in thinking.
association area, the part of the brain that helps one remember. It brings together the impulses from the sensory areas, sorts them, and sends them on to the motor area.
a stig ma tism (ə stig′mə tizm), a defect of the eye that prevents rays of light from coming to a focus at a single point on the retina, thus causing a blurred image.
au di om e ter (ô′di om′i tər), an instrument for measuring the power of hearing.
au di to ry (ô′di tō′ri) **center,** the part of the brain that receives the impulses from the ear.
auditory nerve, the nerve that carries impulses from the inner ear to the brain.

Bab bitt (bab′it) **metal,** a metal made of tin and antimony.
ball bearing, a bearing that contains metal balls to lessen friction.
bat ter y (bat′ər i), a set of two or more electric cells that produce electric current.
be hav ior (bi hāv′yər), the response of a living thing to a situation; the activities of a living thing.
Blat ti dae (blat′i dē), a family of insects including cockroaches.
blend, an individual with characteristics that are a mixture of those of the parents because of the fact that one trait is not completely dominant over the other.
block and tackle, a combination of pulleys and rope used to lift weights, or otherwise exert a great force.
brake drum, a revolving cylinder attached to the wheel of a vehicle, against which the brake band presses.
brake lining, a tough substance used on brakes to make friction between the brakes and the brake drums on the wheels.

breed true, produce offspring having the same trait or traits as the parents from generation to generation.

brush, a strip of metal or a block of carbon that carries the electric current from the armature of a generator to the outside circuit or from the outside circuit to the armature of a motor.

bry o phyte (brī′ə fīt), any one of the group of plants to which the mosses and liverworts belong.

budding, a method of grafting in which a bud from one tree (scion) is inserted beneath the bark of another (the stock).

cam bi um (kam′bi əm), a layer of delicate growing cells between the bark and wood of trees and shrubs, that forms new wood and bark.

car bu re tor (kär′bə rā′tər), a device for vaporizing gasoline and mixing it with air in a gasoline engine.

carrier waves, radio waves of varying intensities sent out to carry the messages to receiving sets.

cell (electric), a device that produces an electric current by chemical action.

cer e bel lum (ser′i bel′əm), one of the lower parts of the brain, which helps coördinate movements of the body.

cer e brum (ser′i brəm), the upper part of the brain, that enables man to think.

chain belt or **drive,** a band of chain passing over two or more wheels to transmit motion.

charge, give an object an electric charge; supply an object, such as a storage battery, with electrical energy by passing an electric current through it.

chi tin (kī′tin), a hard material in the outer covering of animals such as insects, crabs, lobsters, etc.

Chor da ta (kôr dā′tə) or **chor dates** (kôr dāts′), the large group of animals that have backbones. It includes all vertebrates and a few other animals having a nerve cord and breathing organs arranged as in the vertebrates.

cir cuit (sėr′kit), the complete path of an electric current.

circuit breaker, an object that interrupts the flow of electricity through a circuit.

class, the division next smaller than the phylum in the plan of classification of living things.

clutch, a device by which the engine of a machine can be connected or disconnected from the driving wheels.

coch le a (kok′li ə), the inner ear, shaped like a snail's shell and filled with liquid.

Coe len ter a ta (sē len′tə rā′tə) or **coe len ter ates** (sē len′tər āts), the group of animals including jellyfish, coral, etc.

cold-blooded animal, an animal whose body temperature changes to correspond with the temperature of its surroundings.

Co le op ter a (kō′li op′tər ə), an order of insects including beetles.
com mu ta tor (kom′ū tā′tər), a device for reversing the direction of an electric current.
con cave (kon′kāv), curved like the inside of a circle or sphere.
con den sa tion (kon′den sā′shən), 1. the part of a sound wave in which the air molecules are pressed together. 2. the change of water vapor to liquid water.
con di tioned re flex (kən dish′ənd rē′fleks), an acquired response that is substituted for an inherited response to a certain stimulus.
con duc tor (kən duk′tər), a material through which heat, electricity, or sound can pass easily.
cone, the structure that bears the seeds in the gymnosperms, such as the pine and other evergreens.
con ser va tion (kon′sər vā′shən), the prevention of waste of natural resources through intelligent and careful use of them.
contour farming, a method of laying out fields so that the rows run around the hills instead of up and down them.
con vex (kon′veks), curved like the outside of a sphere.
Critical Period, an interval of time between eras in the geologic history of the earth.
cross-breeding, the mating of plants or animals belonging to different breeds or varieties.
cross-pol li na tion (krôs′pol′i nā′shən), the transfer of pollen from the stamen of one flower to the stigma of another.
Crus ta cea (krus tā′shə), a class of animals including lobsters, shrimps, etc.
cutting, a small piece of root or shoot cut from a plant that will grow into a new plant of the same kind.
cycle, the series of strokes of a piston in the cylinder of an engine.
cylinder, the part of an engine or other device in which a piston slides back and forth.

dam, the mother animal in sheep, cattle, horses, and other four-footed animals.
dead center, the position of the crank of the flywheel of an engine when it is in a straight line with the connecting rod.
dead points, the two points in its journey in a cylinder at which the piston cannot exert a turning force, because the connecting rod and crank are in a straight line.
dec i bel (des′i bel), a unit for measuring the loudness of sound.
de com pose (dē′kəm pōz′), separate a chemical compound into elements or simpler compounds.
de tec tor (di tek′tər) **tube,** a special tube in a radio set in which high-frequency alternating current is changed to a pulsating direct current that corresponds to sound waves.
di a phragm (dī′ə fram), a thin dividing partition.

di cot y le don ous (dī kot′i lē′dən əs) **plant,** a plant with an embryo that has two seed leaves or cotyledons.

dif fer en tial (dif′ər en′shəl), an arrangement of gears that allows for the difference in speed of the two driving wheels, as in turning a corner.

dif fused (di fūzd′) **light,** reflected light that is scattered.

di no saur (dī′nə sôr), one of a group of extinct reptiles.

Dip ter a (dip′tər ə), an order of insects, such as the flies and mosquitoes, having two wings only.

direct current, electric current that flows in one direction only.

direct lighting, the type of lighting in which the light comes directly from the lamp.

disks, the circular parts of a clutch covered with friction-producing material that act to connect or disconnect the engine from the driving gears.

dis trib u tor (dis trib′ū tər), the device in a gasoline engine that sends a current to each spark plug at the proper time.

dom i nant trait (dom′i nənt trāt), the stronger of two opposite traits, that shows itself even when the other trait is part of the inheritance of the plant or animal.

dry cell, a sealed cell for producing electric current, having zinc and carbon electrodes and a paste moistened with ammonium-chloride solution as the active chemical.

ec cen tric (ek sen′trik), a circular device that rotates about a point not its center, used on machines for changing circular motion into back-and-forth motion.

E chi no der ma ta (i kī′nə dėr′mə tə) or **echinoderms** (ē kī′nə dərmz), a group of animals including the starfish and sea urchins.

electric arc, the stream of brilliant light formed as current crosses a short space between one conductor and another.

electric charge, a substance has an electric charge when it has gained or lost electrons so that it is no longer neutral.

electrical friction, the resistance of a conductor to the passage of an electric current.

electrical pressure, the force that tends to make electricity flow through a conductor.

electrical system, the various electrical devices in an engine that produce the sparks in the cylinders and provide for lighting, etc.

e lec trode (i lek′trōd), either of the two poles, or terminals, of a battery or any similar electrical device.

e lec trol y sis (i lek′trol′i sis), the use of an electric current to decompose a melted or dissolved chemical compound into its elements.

e lec tro lyte (i lek′trō līt), a melted or dissolved compound that will conduct an electric current.

e lec tron (i lek′tron), a tiny particle containing a negative charge of electricity.

e lec tro plat ing (i lek′trō plāt′ing), coating an object with metal by using electric current and an electrolyte.

energy, power to make matter move or change.

era (ēr′ə), the largest division of geological time.

e ro sion (i rō′zhən), an eating away or a wearing away.

Eu sta chi an (ū stā′ki ən) **tube,** a tube that leads from the back part of the mouth to the middle ear.

exhaust valve, a valve in an engine through which used steam or gases may pass from the cylinder to the exhaust pipe and out to the open air.

family, in the plan of classification of living things, the family is the division next smaller than the order.

fault, a break in rocks that allows them to move past each other.

fer ti li za tion (fėr′ti li zā′shən), the uniting of the nuclei of male and female reproductive cells.

field magnet, an electromagnet used in a generator to make a strong electric field.

fil a ment (fil′ə mənt), the thread-like wires in an electric light-bulb that glow to give the light.

fire-tube boiler, the type of boiler in which hot gases pass through tubes surrounded by water.

fixed pulley, a pulley that does not move up and down.

fluc tu at ing (fluk′chü āt ing) **current,** a current varying in strength.

flu or es cent (flü ər es′ənt) **lamp,** a lamp without filament that produces light from special materials coating the inside of the glass tubes.

fo cus (fō′kəs), place a lens in such a position that the light rays coming through it make a clear image; the point at which rays of light, heat, etc., meet after being reflected or refracted.

foot-candle, the brightness of the illumination provided by a standard candle at a distance of one foot.

foot-pound, the work done when a force of one pound is moved through a distance of one foot.

force-arm, in a lever, the distance from the force to the fulcrum.

fos sil (fos′il), the hardened remains or trace of an animal or plant.

four-cycle or **four-stroke cycle engine,** an engine in which a series of four strokes of the piston is needed for every push the piston gets.

fre quen cy (frē′kwən si), the number of vibrations per second of the source of a sound; in radio the number of waves per second sent out from the aerial of the sending station.

fric tion (frik′shən), rubbing of one thing against another; resistance to motion of surfaces that touch each other.

fric tion al (frik′shən əl) **electricity,** electric charges produced by rubbing one material on another.

fuel system, the parts of the gasoline engine that have to do with supplying the gasoline to the engine.

ful crum (ful′krəm), the place where a lever is rested or supported.
fun gi, singular **fun gus** (fun′jī, fung′gəs), the plants of the thallophyte group that do not have chlorophyll.
fuse (fūz), a part of an electric circuit that will melt and break the circuit if the current gets dangerously large.

gal va nom e ter (gal′və nom′i tər), an instrument for determining the presence, strength, and direction of an electric current.
gear, a wheel having teeth that fit into the teeth in another wheel.
gear-shift lever, a long transmission lever by which the position of automobile transmission gears can be changed.
gen er a, singular **ge nus** (jen′ər ə, jē′nəs). Families of plants and animals are divided into genera.
gen er a tion (jen′ər ā′shən), the offspring of a given parent or parents, considered as a single step in the series of descendants from any parent or parents.
gen er a tor (jen′ər ā′tər), 1. an apparatus for producing electric current. 2. a machine for changing mechanical energy into the energy of an electric current.
ge ol o gist (ji ol′ə jist), a scientist who studies the structures and changes of the earth.
gill, a feather-like structure through which fish and other water animals take in oxygen from the water.
gill cover, a plate-like structure on the head of a fish that covers and protects the gills.
gill rakers, spiny projections on the gill-supporting bones that sift out solid particles from the water passing over the gills.
giz zard (giz′ərd), a bird's second stomach, where the food from the first stomach is ground up fine.
grading, a method of animal-breeding in which the sire is pure-bred, but the dam is not.
grafting, a method of obtaining desired characteristics in plants by applying buds or twigs of one kind to the rooted stems of another kind in such a way that they will grow together.
grid, the plates of a storage battery.
gym no sperm (jim′nə spėrm), a plant that bears its seeds in cones.

habit, a tendency to do a certain thing in a certain way.
hab i tat (hab′i tat), the place where an animal or plant naturally lives or grows.
head (of water), the height of water above a certain place.
He mip ter a (hi mip′tər ə), an order of insects including bugs and lice.
he red i ty (hi red′i ti), the tendency of offspring to resemble their parents.
hi ber na tion (hī′bər nā′shən), spending the winter in sleep, as bears and some other wild animals do.

horse-power, a unit for measuring the rate at which a machine can do work; the power necessary to do 550 foot-pounds of work in a second.

hy brid (hī′brid), the offspring of two animals or plants of different races, varieties, or species.

hy drom e ter (hī drom′i tər), an instrument for finding the densities of liquids.

Hy me nop ter a (hī′mə nop′tər ə), an order of insects including the ants, bees, and wasps.

ig ne ous (ig′ni əs) **rock,** rock that has melted and hardened.

image, a picture of an object such as is formed by a light that passes through a lens or is reflected by a mirror.

imprint, a mark made by pressure, as a footprint in sand.

impulse, the message sent along a nerve from the place of stimulation to the brain, or from the brain to a muscle.

in can des cent (in′kən des′ənt), glowing with heat.

inclined plane, a sloping surface.

indirect lighting, the method of lighting in which the light comes to the room by reflection from the ceiling.

in duc tion (in duk′shən) **coil,** a small transformer consisting of a primary coil wound with insulated wire and a secondary coil fitted over the primary, wound with many thousands of turns of small insulated wire.

induction motor, a motor using only alternating current and having no electrical connections to the armature from the outside.

in er tia (in ėr′shə), tendency of all objects to stay still if still or, if moving, to go on moving in the same direction unless acted on by some outside force.

inherited response, a response that is not learned, but is purely mechanical.

In sec ta (in sek′tə), a class of arthropods including the flies, butterflies, beetles, etc.

in series, connected in an electrical circuit in such a way that each electron must go through every device in the series.

in stinct (in′stingkt), or **in stinc tive** (in stingk′tiv), **behavior,** a kind of behavior that an animal inherits from its parents.

in su la tor (in′sə lā′tər), material that prevents the passage of electricity or heat; a non-conductor.

intake valve, the valve through which the mixture of gas and air from the carburetor enters the cylinder of a gasoline engine.

internal-combustion engine, an engine that burns fuel inside itself.

in ver te brate (in vėr′ti brāt), an animal without a backbone.

in vol un tar y (in vol′ən tãr′i) **action,** an action over which one has no control.

i on (ī′ən), one of the charged particles into which some materials are broken up when they are dissolved; a charged particle in the air.

jack, a machine for lifting heavy weights short distances.
jackscrew, a jack for raising weights, operated by a screw.
jeweled bearing or **jewel,** a bearing made of a small piece of precious stone or other mineral, used in watches.

kil o cy cle (kil′ə sī′kəl), a unit equal to 1000 cycles, used especially in radio for measuring the frequency of electric waves.
kil o watt (kil′ə wot′), a unit of electric power equal to 1000 watts.
kilowatt-hour, 1000 watt-hours of electric energy.
ki net ic (ki net′ik or kī net′ik) **energy,** energy possessed by a body because of its motion.

lar ynx (lar′ingks), the upper end of the windpipe, where the vocal cords are located.
len ti cel (len′ti sel), a pore in the bark of stems through which the cells beneath obtain oxygen.
Lep i dop ter a (lep′i dop′tər ə), an order of insects including butterflies and moths.
lev er (lev′ər or lē′vər), a bar working on a pivot or support, called a fulcrum.
li chen (lī′kən), a plant of the thallophyte group, that consists of an alga and a fungus growing together.
light meter, an instrument for measuring the amount of light needed for different purposes and the kind and number of lamps necessary to supply this light.
light rays, the lines in which light travels through the air.
liv er worts (liv′ər wėrts′), plants of the bryophyte group, for the most part with flattened bodies that are often branched.
lu mi nous (lü′mi nəs or lū′mi nəs), shining by its own light.

mag net ic (mag net′ik) **field,** the area in which the force of a magnet acts.
mag ne to (mag nē′tō), a small machine that uses permanent magnets for producing electric current.
mam mal (mam′əl), an animal that suckles its young.
mass selection, a method of improving plants in which all the seed selected is planted together.
mechanical advantage, the ratio of the force produced by a machine to the force applied to it.
mechanical energy, energy possessed by moving bodies or by bodies because of their position.
me dul la (mi dul′ə), the lowest part of the brain. The medulla is continuous with the spinal cord.
met a mor phic (met′ə môr′fik) **rock,** rock changed in its structure by natural agents such as pressure and heat.
mi grate (mī′grāt), pass from one region to another with the seasons, as many birds do.

mim ic ry (mim′ik ri), the close resemblance of one animal to another animal.

Mol lus ca (mə lus′kə) or **mollusks** (mol′əsks), a group of animals including snails and clams.

moss, a small leafy plant belonging to the bryophyte group.

motor area, the part of the brain that sends impulses to the muscles of the body.

movable pulley, a pulley that is attached to the weight to be moved and moves with it.

mu ta tion (mū tā′shən), a new trait that breeds true.

Myr i ap o da (mir′i ap′ə də), a class of arthropods including centipedes.

negative charge, one kind of electrical charge that a body may have, consisting of an excess of electrons over protons.

non-conductor, a substance that does not readily conduct heat, electricity, etc.

objective lens, in a compound microscope or telescope, the lens nearest the object to be looked at.

oc tave (ok′tāv), the interval between one musical note and another having twice or half as many vibrations.

offspring, the children of a pair of parents.

o paque (ō pāk′), not letting light through.

order, in the classification of plants and animals, the group below or smaller than a class, but larger than a family.

Or thop ter a (ôr thop′tər ə), an order of insects including grasshoppers, cockroaches, etc.

overshot wheel, a water-wheel turned by the force of water flowing over the top of the wheel.

overtone, a higher tone heard along with the main or fundamental tone of a vibrating body. It is produced by the body vibrating in parts.

parallel circuit, an electrical circuit in which electrical devices are connected so that some of the electrons go through each device without going through the others.

ped i gree (ped′i grē) **system,** a system of keeping records of the ancestry of animals.

ped i greed (ped′i grēd), an animal whose ancestry is known for several generations.

Pel ton (pel′tən) **wheel,** a type of undershot wheel having a row of curved buckets on the rim, against which water is shot from a nozzle.

per cus sion (pər kush′ən) **instruments,** musical instruments that are played by striking them.

period, the division of geologic time next smaller than the era.

per i scope (per′i skōp), a device consisting of an arrangement of mirrors or prisms in a tube, by which a view at the surface of water or land, etc., may be seen from below or behind.

pet i ole (pet′i ōl), the stem or stalk of a leaf.

phos pho res cent (fos′fə res′ənt) **organ,** a structure that gives off light without heat.

phy lum (fī′ləm), the largest group into which plants or animals are divided.

pistil, the seed-bearing part of a flower.

pis ton (pis′tən), a flat, round piece of wood or metal, fitting closely inside a tube, or hollow cylinder, in which it is moved back and forth by some force, such as steam pressure.

pitch, in music, the degree of highness or lowness of a sound; of a screw, the distance between the centers of two threads.

plane mirror, a flat mirror.

plat y pus (plat′i pəs), the duckbill, one of the egg-laying mammals of Australia.

pollen tube, the tube that grows out of the pollen grain down through the style to the ovary in a flower.

Pol y chaet (pol′i kēt) **worm,** one of the group of worms having many bristles and including most of the common sea worms.

pol yp (pol′ip), a simple form of water animal not much more than a sac-like stomach with tentacles around the edge for gathering in the food.

Po rif er a (pō rif′ər ə), the sponges, a group of invertebrate animals having many tiny pores in their bodies.

positive charge, one kind of electrical charge that a body may have, consisting of an excess of protons over electrons.

power, energy or force that can do work; the rate at which a machine can do work.

primary coil, the coil of a transformer that, by its magnetic effect, generates current in another coil, called the secondary coil.

pri mate (prī′māt), any one of the highest order of animals, including monkeys and apes.

prism (prizm), a solid, triangular-shaped piece of glass that will separate white light passing through it into the colors of the rainbow.

prog e ny (proj′i ni), offspring or descendants of a pair of parents.

progeny-performance method, a method of improving plants or animals by keeping a separate record of the offspring from different individuals and breeding only those from parents that produce the best offspring.

protective col or a tion (kul′ər ā′shən), the coloration of animals that makes it hard to distinguish them from their surroundings.

pro ton (prō′ton), a tiny particle carrying a positive charge of electricity. A proton is a part of an atom.

Pro to zo a (prō′tə zō′ə), the group of one-celled animals.

psy chol o gist (sī kol′ə jist), one who studies the science of the mind.
pter i do phyte (ter′i dō fīt′), the group of plants that includes the higher non-seed-bearing plants, the ferns and related plants.
pulley, a wheel with a hollowed rim in which a rope can run, and so lift weights or change the direction of the pull.
pulsating current, an electric current that changes from a strong one to a weak one, back to a strong one, and so on.
pure-bred, used to describe an animal whose ancestry is known for several generations.

quality, the character of a tone that makes it possible to tell it from another tone of the same pitch and intensity. The combination of original tone and overtones affects the quality of a tone.

radiant energy, energy in the form of visible or invisible rays from some heated source.
ra di a tor (rā′di ā′tər), the part of the cooling system of a gasoline engine in which the hot water from around the cylinders is cooled by the rapid giving off of heat into the air.
ra di o ac tive (rā′di ō ak′tiv), used to describe an element like radium that gives out radiant energy all the time as it changes into other substances.
radio waves, electromagnetic waves that travel out from an aerial in radio broadcasting; a form of radiant energy.
rar e fac tion (rãr′i fak′shən), the part of a sound wave in which the air molecules are spread apart.
reaction time, the time that it takes for a person to react to a stimulus.
receiver, the part of the telephone that receives electric current from the transmitter and changes it back to sound waves.
re ces sive (ri ses′iv) **trait,** in heredity, a character that does not show itself when the dominant trait is present.
re cip ro cat ing (ri sip′rə kāt ing) **motion,** back-and-forth motion, such as that used with a tire pump.
reed, a thin piece of wood or metal that produces the sound in certain musical instruments, such as a clarinet, saxophone, etc.
re flect (ri flekt′), throw back, as light, heat, sound, etc.
reflex act, an action that takes place without one's willing it to take place.
re fract (ri frakt′), bend from a straight course, as light in passing through a lens or prism.
re frac tion (ri frak′shən), the bending of light.
regularly reflected, a whole beam of light reflected together, as sunlight is reflected from a mirror.
rep tile (rep′til), a cold-blooded vertebrate animal that creeps or crawls, such as a snake or a lizard.
re sist ance (ri zis′təns), in electricity, friction.

res o na tor (rez′ə nā′tər), a device for making sound louder and longer by reflection or sympathetic vibrations.
ret i na (ret′i nə), the layer of cells at the back of the eyeball that is sensitive to light and receives the images of things looked at.
re vers ing (ri vėr′sing) **prism,** a combination of prisms that reflects light four times and turns an inverted image right-side-up.
rhi zoid (rī′zoid), a thread-like structure that serves as a root in moss plants.
roller bearing, a bearing used for heavy machinery, in which a set of small rollers turns between a shaft or wheel and its support.
rolling friction, the friction between a roller or a wheel and a surface.
ro ta ry (rō′tə ri) **motion,** circular motion, such as that of a wheel.
ro tor (rō′tər), the rotating part of a machine or apparatus.

safety valve, a valve in a boiler that allows steam to escape when the pressure becomes too great.
sci on (sī′ən), the shoot or bud cut for grafting onto a rooted plant.
screw, a type of inclined plane consisting of a cylinder having a spiral ridge running around it.
screw pro pel ler (prō pel′ər), a propeller that acts on air or water in the way an ordinary screw acts on wood or metal.
secondary coil, the coil of a transformer in which current is generated by the magnetic action of another coil, called the primary coil.
segment, a ring-like part of an animal such as the earthworm.
se lec tion (si lek′shən), a method of improving plants and animals by choosing, for growing and breeding purposes, individuals showing the best qualities.
se lec tive (si lek′tiv) **cutting,** a plan for conserving trees in which only a certain kind and number of trees are cut from a forest at any one time.
self-pol li na tion (self′pol′i nā′shən), the transfer of pollen from a stamen to the stigma of the same flower.
semi-direct lighting, lighting in which part of the light is reflected from the ceiling, and part is diffused into the room through a translucent bowl under the light.
sending key, the part of the telegraph sending apparatus that is pressed down and released to complete or break the electric circuit.
sen so ry ar e a (sen′sə ri ãr′i ə), the part of the brain to which the nerves of the different sense organs are connected.
series circuit, a method of connecting electrical devices together so that each electron must go through every device in the circuit.
short circuit, the path of an electric current when it goes back to the generator without passing through any electrical device.
simple machine, a simple device that transmits and modifies force.
sire (sīr), the male parent of an animal.
sleep movement, the movement of flowers and leaves at night.

slide valve, one kind of valve in a steam engine that moves back and forth to let steam first into one end of the cylinder and then into the other end. At the same time the slide valve regulates the escape of used steam from the cylinder.

sliding friction, friction created when two surfaces slide past each other.

slip ring, insulated rings on the shaft of an alternating-current generator that help transmit the current from the armature to the outside circuit.

so nom e ter (sō nom′i tər), an instrument for experimenting with vibrating strings.

sounder, a receiving instrument by whose sounds a telegraph message is read.

sounding-board, a board behind the strings of a piano that reënforces the sound made when the hammers strike the strings.

sound in su la tor (in′sə lā′tər), a porous or flexible material that transmits sound waves very poorly.

sound-level meter, an instrument for measuring the loudness of sound.

sound wave, one of the series of motions of air molecules that transmits vibrations from the vibrating source of sound to the ear. A complete sound wave includes one condensation and one rarefaction.

spe cies (spē′shiz), in the classification of plants and animals, the division next smaller than a genus; all the plants or animals of a single kind.

spec tral (spek′trəl) **color,** one of the pure colors of the spectrum.

spec trum (spek′trəm), the band of colors into which white light is separated when it is passed through a prism.

sper ma to phyte (spėr′mə tō fīt′), a seed-bearing plant.

stal lion (stal′yən), a male horse useful for breeding purposes.

Standard Pitch, a pitch, also known as International Pitch, based on a frequency of 435 vibrations per second for A above middle C. All orchestras are supposed to use this pitch, and most pianos are tuned to it.

starting motor, the part of the electrical system in an automobile, etc., that starts the gasoline engine.

static electricity, electric charges on bodies such as are produced by rubbing one material on another.

steam chest, the box-like part of a steam engine that covers the slide valve and the openings into the cylinders.

steam tur bine (tėr′bin or tėr′bīn), an engine or motor in which a wheel with vanes is made to revolve by the force of steam.

step-down trans form er (trans fôr′mər), a transformer that reduces the voltage of an alternating electric current.

step-up transformer, a transformer that increases the voltage of an alternating electric current.

stim u lus, plural **stim u li** (stim′ū ləs, stim′ū lī), anything that causes a response in a living thing.
stock, the rooted plant onto which twigs and buds are grafted.
storage battery, three or more storage cells connected together.
storage cell, a cell for generating current that can be recharged by running a current of electricity through it.
strip cropping, planting different crops in strips of equal width, running across the slopes instead of up and down.
sym pa thet ic vi bra tion (sim′pə thet′ik vī brā′shən), vibration produced in one body by sound waves of the same number of vibrations per second in another body.
syn chro nous (sing′krə nəs), occurring at the same time, or going on at the same rate and exactly together.

taste buds, small, flask-shaped bodies on the surface of the tongue believed to be special taste organs.
tel e type writ er (tel′i tīp′rīt′ər), a machine that receives the messages from a telegraph receiver and automatically types them out.
tel e vi sion (tel′i vizh′ən), transmission and reproduction of the images of distant persons or scenes by any device that changes light rays into radio waves and then back into light rays.
ten ta cle (ten′tə kəl), a slender, flexible appendage in animals that serves as an organ of touch, etc.
ter rac ing (ter′ə sing), a method of preventing soil erosion by building the long, steep slopes of hillsides into short, gradual slopes, almost like steps.
thal lo phyte (thal′ō fīt), one of the group of plants, including the fungi, algae, and lichens, in which the plant body is not differentiated into true root, stems, and leaves.
top-soil, the uppermost layer of soil, about eighteen inches thick.
tra che al (trā′ki əl) **gills,** outgrowths from the body covering of the aquatic stages of some insects by means of which oxygen is obtained from the water. The air tubes of the insect extend into such gills.
trait (trāt), a characteristic.
trans form er (trans fôr′mər), a device for changing the voltage of an alternating electric current.
trans lu cent (trans lü′sənt or trans lū′sənt), letting light through, but not transparent.
trans mis sion gears (trans mish′ən gērs), gears forming part of the transmission system of an automobile.
transmission system, the part or parts of an automobile involved in transmitting power from the engine to the rear wheels.
trans mit ter (trans mit′ər), the part of a telephone into which one speaks; the part of a telegraphic instrument by which a message is sent.
trans par ent (trans pãr′ənt), easily seen through.

trial-and-error (behavior), making all possible attempts and eliminating the ones that bring unsatisfactory results.
tri lo bite (trī′lə bīt), an extinct member of the arthropod group that lived in the Paleozoic Era.
tro pism (trō′pizm), the response of plants to stimuli from a certain direction.
tur bine (tėr′bin or tėr′bīn), an engine or motor in which a wheel with vanes is made to revolve by force of water, steam, or air.

un con for mi ty (un′kən fôr′mi ti), the surfaces between layers of older rocks and layers of newer rock, showing that changes have occurred between the times of formation of the layers.
undershot wheel, the type of water-wheel turned by water flowing under the wheel.

var i a tion (vãr′i ā′shən), the differences between living things of the same species.
ver te brate (vėr′ti brāt), an animal with a backbone.
vocal cords, membranes in the throat, the lower of which can be pulled tight or loosened to help make the sounds of the voice.
volt (vōlt), the unit used to measure electrical pressure.
volt age (vōl′tij), electrical pressure, measured in volts.
volt me ter (vōlt′mē′tər), an instrument for measuring the number of volts of an electric circuit.
vol un tar y (vol′ən tãr′i) **action,** an action of the body that is willed to happen.

warm-blooded animal, an animal that keeps an almost even body temperature, regardless of the temperature of the air or water that surrounds it.
water jacket, a hollow space filled with water around the cylinder of a gasoline engine, to prevent overheating of the cylinder.
wa ter-vas cu lar (wô′tər vas′kū lər) **system,** the internal structure peculiar to the Echinoderm group of animals.
watt (wot), a unit for measuring power, about 44 foot-pounds per minute; in electricity a watt is the power of a current of one ampere flowing under a pressure of one volt.
watt-hour (wot′our′), the amount of energy used by a device that uses one watt for one hour.
watt-hour meter, an instrument that measures the number of watt-hours of electric energy used in a building over a period of time.
wedge, a piece of wood or metal with a thin edge used in splitting, separating, etc.
weight-arm, the distance from the weight to the fulcrum, in a lever.
wheel and axle, a simple machine consisting of a wheel or a crank fixed to a bar or shaft.
work, exerting a force through a distance.

INDEX

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